Appendix K: Climate impacts and adaptation actions for bull trout

Figure K.1. Bull trout.

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners focused their assessment on a suite of case study species, vegetation systems, and regions chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for bull trout (*Salvelinus confluentus*).

The bull trout is a cold-water fish found in streams and lakes across northwestern North America. The bull trout requires especially cold, clean, complex, and connected habitats, and relies on access to headwater streams for annual spawning and feeding migrations.[2] In the transboundary region of Washington and British Columbia, barriers to bull trout movement are presented by both natural factors (e.g., low summer streamflows, high summer stream temperatures) and human factors (e.g., culverts, dams, and introduction of non-native fish).

Future climate change may present additional challenges and needs for bull trout habitat connectivity.[3-4] First, climate change may impact bull trout core habitat and dispersal habitat in ways that may make them more or less permeable to movement. Second, existing bull trout core habitat and dispersal habitat may be distributed in ways that make them more or less able to accommodate climate-driven shifts in the range of bull trout. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[5] However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for bull trout habitat connectivity. To address these needs, we describe here a novel effort to identify and address potential climate impacts on bull trout habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary bull trout habitat connectivity, project partners created a conceptual model that identifies the key hydrologic and landscape features and processes expected to influence bull trout habitat connectivity, which of those are expected to be influenced by climate, and how (Appendix K.2). Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The bull trout conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to bull trout habitat connectivity.

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[i] This report is Appendix K of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

Project participants used conceptual models in conjunction with maps of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on bull trout connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, we relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[7,8] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[9] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[10] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[11]

Key impacts on transboundary bull trout habitat connectivity identified via this approach include changes in areas of climatic suitability, changes in stream temperature, and changes in precipitation and stream flows.

Changes in areas of climatic suitability

Climate change may impact bull trout habitat connectivity by changing the extent and location of areas of climatic suitability for bull trout; this may render some existing core habitat areas and dispersal areas unsuitable for bull trout, and/or create new areas of suitability. Currently, climatic niche models (CNM) are unavailable for bull trout across the transboundary region. However, analyses are available for Washington that estimate changes in areas of bull trout habitat suitability based on projected changes in stream temperature. Areas with a high (>90%) probability of stream occupancy by juvenile bull trout are projected to dramatically decline by the 2080s for Washington, with smaller, more fragmented areas of high probability remaining only at high elevations within the Cascade Range (Appendix K.3).[12] Another analysis that used air temperature-elevation relationships as a proxy for stream temperature also predicted that warming will result in smaller, more isolated patches of suitable bull trout habitat in the interior Columbia Basin in Washington, with extensive extirpation projected under high levels of warming.[ii,13]

Changes in stream temperatures

Bull trout are highly sensitive to water temperature, and are the most cold-water dependent fish in the Pacific Northwest. As discussed above, it may thus be expected to experience a decline in suitable habitat if projected increases in air temperature and declines in summer streamflow result in steam temperature increases that exceed the thermal threshold of the species. Projected reductions in spring snowpack may also contribute to stream temperature increases by removing a critical source of cold water during spring and summer (Appendix K.4: Spring (April 1st) Snowpack). Modeled current and projected future stream temperatures are available for the western United States (Appendix 4: Stream Temperatures).[14] These models project that stream temperatures in the transboundary region will increase, which would likely reduce the total area of suitable habitat for bull trout as well as connectivity among remaining areas of suitable habitat.[iii]

[ii] The high warming scenario was a ~5°C temperature increase, which is within the range projected for 2080s under a high carbon emissions scenario.

Changes in streamflows

Climate change is projected to alter streamflows in ways that are likely to negatively affect bull trout habitat connectivity. Projected increases in the frequency and intensity of extreme precipitation events during the fall, winter and spring (Appendix K.4: Maximum 24-hour Precipitation) may lead to flood events that can flush eggs from bull trout nests, decreasing the quality of bull trout core habitat.[15] Increased spring precipitation and earlier snowmelt are projected to result in increased spring runoff at high elevations, but decreased runoff at lower elevations (Appendix K.4: Total Spring Runoff). Conversely, summer runoff is projected to decrease at high elevations, but perhaps slightly increase at lower elevations (Appendix K.4: Total Summer Runoff). Lower summer flows could result in increased stream temperatures, leading to further reductions in habitat quality and thermal barriers to movement. In addition, projected reductions in summer flows may create physical migration barriers for bull trout if water levels are too low for fish passage.

Changes in disturbance regime

Climate change may affect bull trout habitat connectivity by increasing the frequency and severity of summer drought (Appendix K.4: Dry Spell Duration; Water Deficit, July-September) and increasing the risk of wildfires (Appendix K.4: Days with High Fire Risk). Summer drought and a longer fire season and increase in area burned could affect riparian habitat important for shading streams and maintaining low stream temperatures.[16] In addition, post-fire floods and debris flows associated with high intensity fires can cause degradation of bull trout habitat. Increased wildlife risk may thus be expected to affect bull trout connectivity by reducing the amount and/or quality of core habitat and dispersal habitat.

Adaptation responses

After identifying potential climate impacts on bull trout habitat connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts (Appendix K.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on bull trout habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in bull trout distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts to bull trout habitat connectivity

Actions to address increasing stream temperatures, which can reduce habitat quality and create thermal barriers to bull trout movement, include:

- Restoring riparian vegetation, which will help shade streams and reduce stream temperatures.
- Excluding cattle from riparian areas to prevent loss of vegetative cover.
- Managing forests to reduce impacts from high intensity fires, which may help maintain riparian shading and lower stream temperatures.[17]
- Investigating the feasibility and benefit of manually transporting bull trout around thermal barriers in streams.

Actions to address declining summer streamflows, which create physical and thermal barriers to bull trout movement, include:

- Managing forests to maximize groundwater infiltration.

- Using dam release events to maintain water levels and stream temperatures adequate for fish passage.
- Identifying and mitigating barriers such as dams or poorly designed road crossings or culverts to promote fish passage.

Actions to address the potential for climate change to impact connectivity through more frequent and severe wildfires include:

- Using prescribed burns and thinning to reduce the risk of catastrophic wildfires that could negatively impact bull trout core habitat and dispersal habitat.
- Prioritizing implementation of fire risk reduction efforts in riparian areas and forests adjacent to suitable bull trout habitat.

Enhancing connectivity to facilitate range shifts

Actions that may help bull trout adjust its geographic distribution to track shifts in its areas of climatic suitability include:

- As stream temperatures warm, consider the benefits and risks of moving bull trout to currently unoccupied cold-water streams.

Spatial priorities for implementation

- Cold-water refuges – areas within streams that have persistently lower temperatures than other stream areas, due to the presence of deep pools, overhanging vegetation, undercut banks, or ground water interactions.[18] Efforts to maintain or restore cold water refuges may promote bull trout habitat quality and movement.
- Currently climatically suitable areas for bull trout that are projected to remain climatically suitable (note that these may or may not overlap with areas identified as cold water refuges).[13,13]
- Riparian areas, particularly those adjacent to cold water refuges or areas projected to remain or become climatically suitable for bull trout.

Policy considerations and research needs

Policy actions

Policy actions for addressing climate impacts on bull trout connectivity include:

- Using the British Columbia Forest Range Act as a tool to help designate additional protection for riparian areas along critical stream reaches for bull trout.
- Monitoring bull trout habitats for suitability and being prepared to address and/or modify the legal context for management. In the United States, bull trout is listed as threatened under the Endangered Species Act, requiring protection of critical habitat; these areas may change with future warming.
- For stream reaches that may warm to an extent that management actions are unlikely to be sufficient to maintain bull trout populations, evaluating whether to continue directing management resources to these areas, or to allow bull trout to decline in these areas in order to redirect resources to areas likely to maintain suitability or become newly suitable.

- Securing water rights to maintain moisture in riparian areas and wetlands that promote cold-water refuges and dispersal through otherwise unsuitable habitat.
- Coordinating with transportation planning agencies to minimize road impacts on bull trout connectivity.

Research Needs

Future research that could help inform bull trout habitat connectivity conservation under climate change includes:

- Developing aquatic habitat connectivity models for bull trout. These models would help identify significant barriers to bull trout movement and priority areas for barrier mitigation.
- Identifying areas that will remain cold enough to support bull trout across a range of climate scenarios. This will require identifying current suitable habitat and projecting potential changes in both stream temperatures and stream flows. This type of research is in progress in the U.S.,[12,13] but similar work is necessary in British Columbia; a transboundary assessment would be preferable, in order to avoid discrepancies and subsequent interpretation challenges at the border.
- For bull trout habitat that is only moderately likely to maintain suitability,[12,13] or to maintain it only for a limited time horizon, evaluating the degree to which management actions, such as riparian restoration, could make the difference between bull trout persistence and decline.
- Identifying movement barriers among cold water refuges and among areas of persistent bull trout habitat suitability. This would help prioritize locations for barrier mitigation efforts and other stream restoration and protection efforts.
- Developing fine-scaled, transboundary models of riparian corridor location and quality. These maps could help identify high quality riparian habitat that could provide shading and lower stream temperatures, or, alternatively, areas in need of riparian restoration to help maintain cool stream temperatures.

References

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6. Cross, M.S., et al. 2012. The Adaptation for Conservation Targets (ACT) framework: a tool for incorporating climate change into natural resource management. *Environmental Management* 50:341–351.

7. Washington Wildlife Habitat Connectivity Working Group. 2010. Washington Connected Landscapes Project: Statewide Analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA. www.waconnected.org.

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Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as “gatekeepers” of flow across a landscape.[iv]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[v] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term “corridor” is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

[iv] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).
[v] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices K.1-4

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For bull trout, these materials include:

Appendix K.1. Habitat connectivity models
Appendix K.2. Conceptual model of habitat connectivity
Appendix K.3. Projected probability of juvenile bull trout occupancy
Appendix K.4. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[7,8] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[9] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[10] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[11]

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig. K.2):

i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.
ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).
iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at:
https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

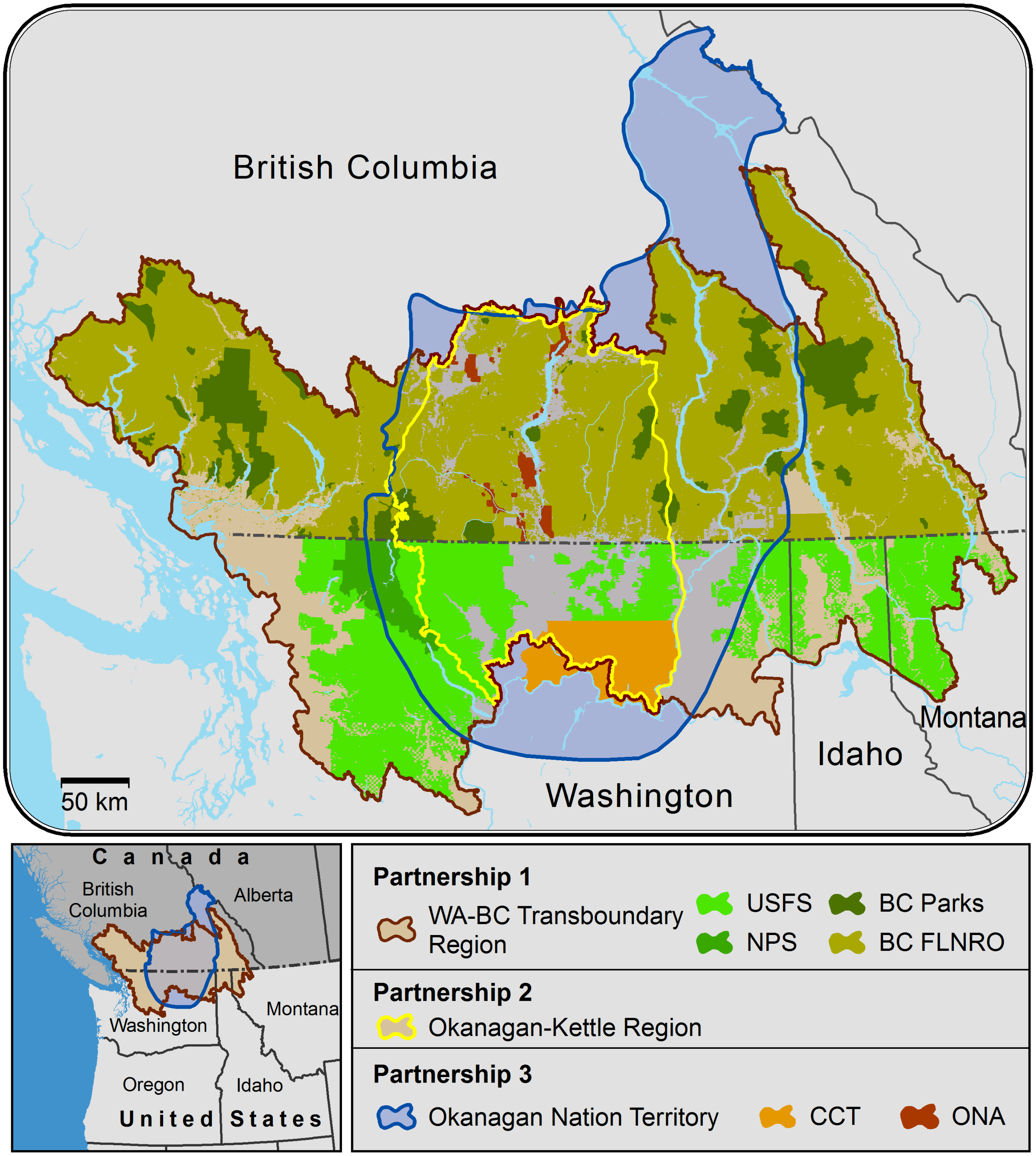


Figure K.2. Project partners and assessment areas.

Appendix K.1. Habitat Connectivity Models

Habitat connectivity models are available from the Washington Connected Landscapes Project.[vi] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia.

a) **WHCWG Statewide Analysis: Landscape Integrity Corridor Network.[7]** This map shows corridor networks connecting core habitat areas (green polygons) for areas of high landscape integrity (e.g., areas with few roads, agricultural areas, or urban areas). Corridors are represented as yellow areas, with resistance to movement increasing as yellow transitions to blue. Green areas represent large, contiguous core areas of high landscape integrity. The northern extent of this analysis falls just north of Kamloops, BC.

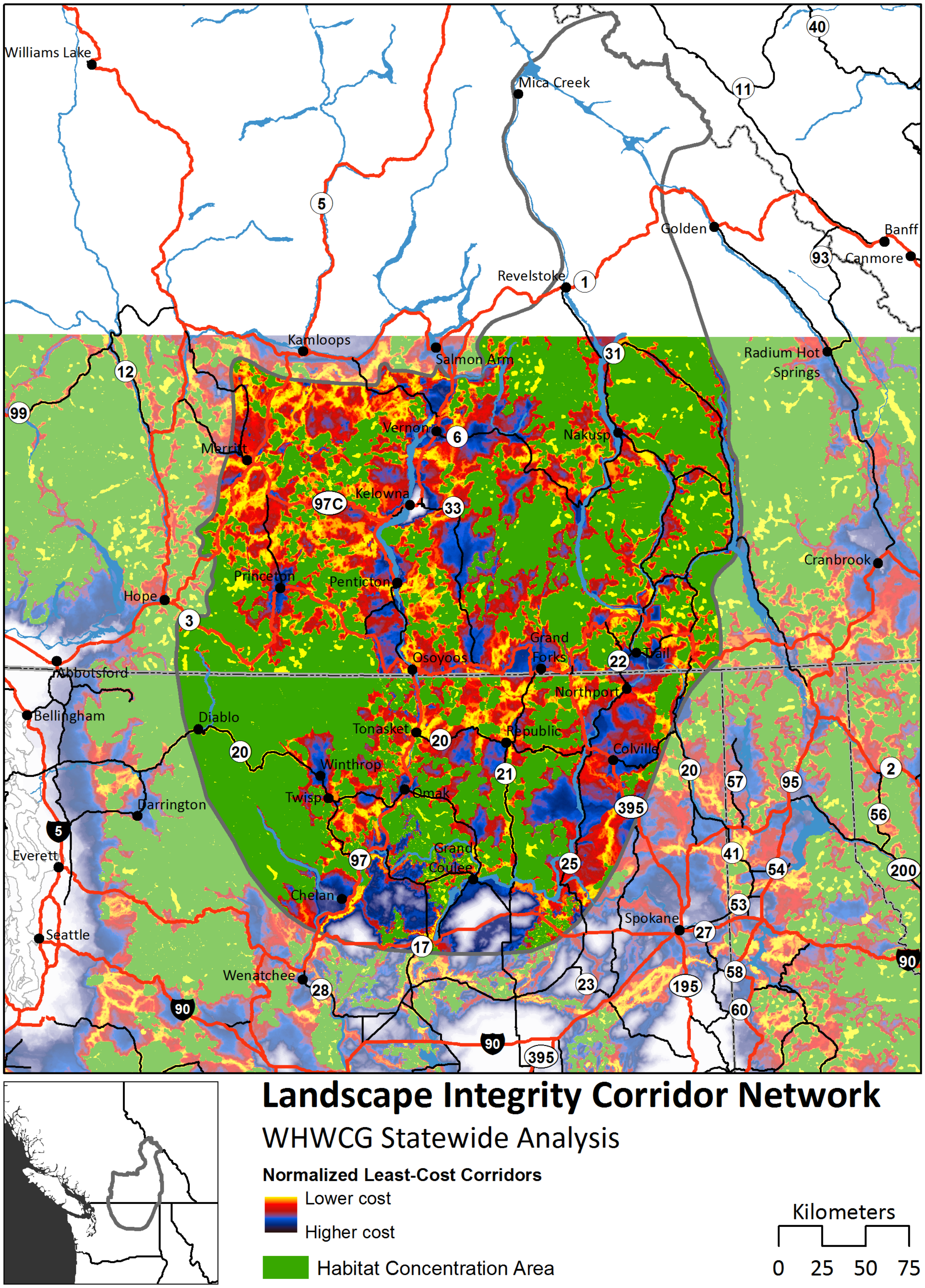
b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).[8]** This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 ^{o}C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

While these models were not created with aquatic connectivity in mind, they may be useful for bull trout given the relationship between terrestrial habitat quality and connectivity, and aquatic habitat quality and connectivity.

[vi] For detailed methodology and data layers see http://www.waconnected.org.

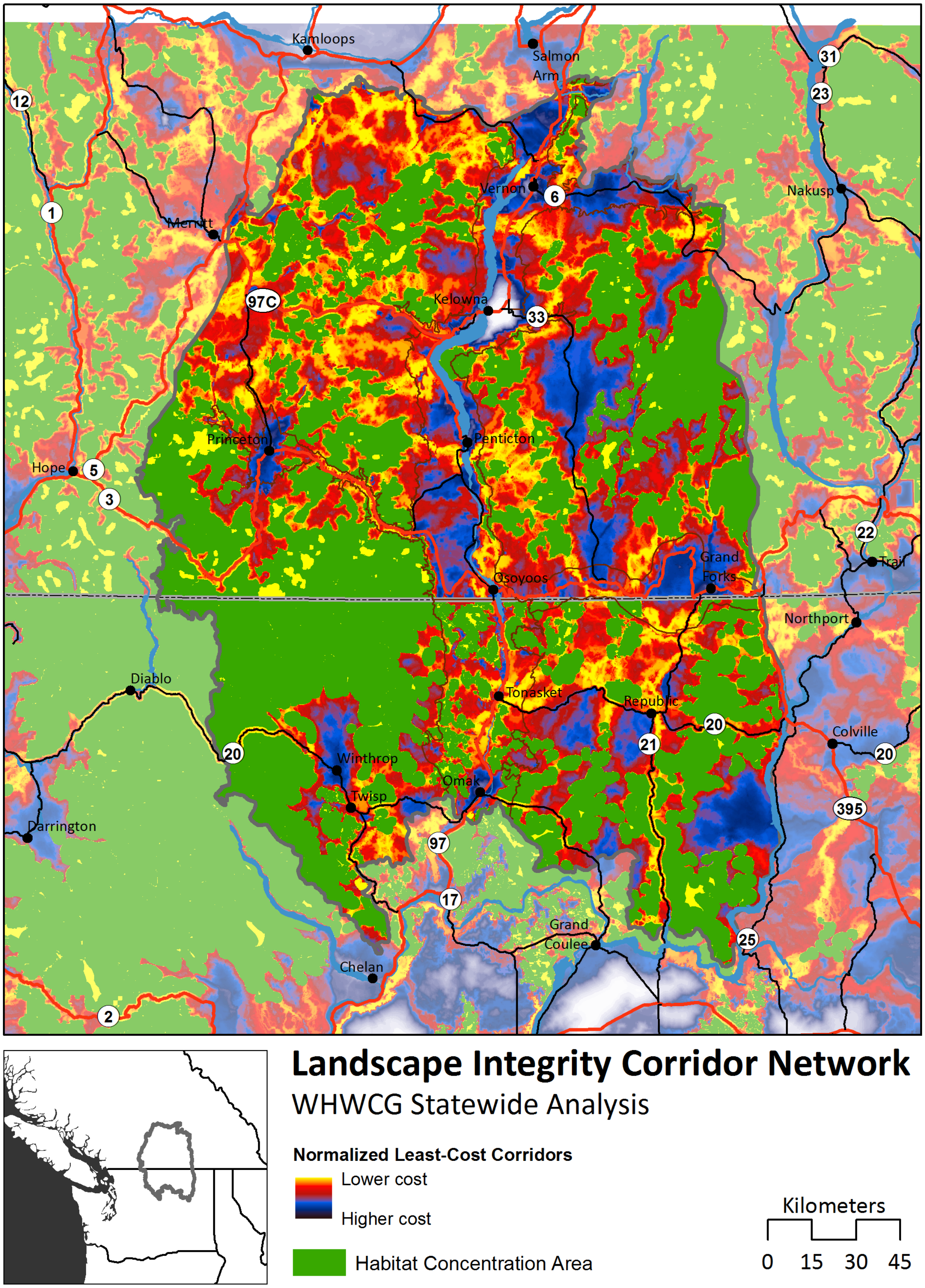
Appendix K.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

i) Extent: Okanagan Nation Territory



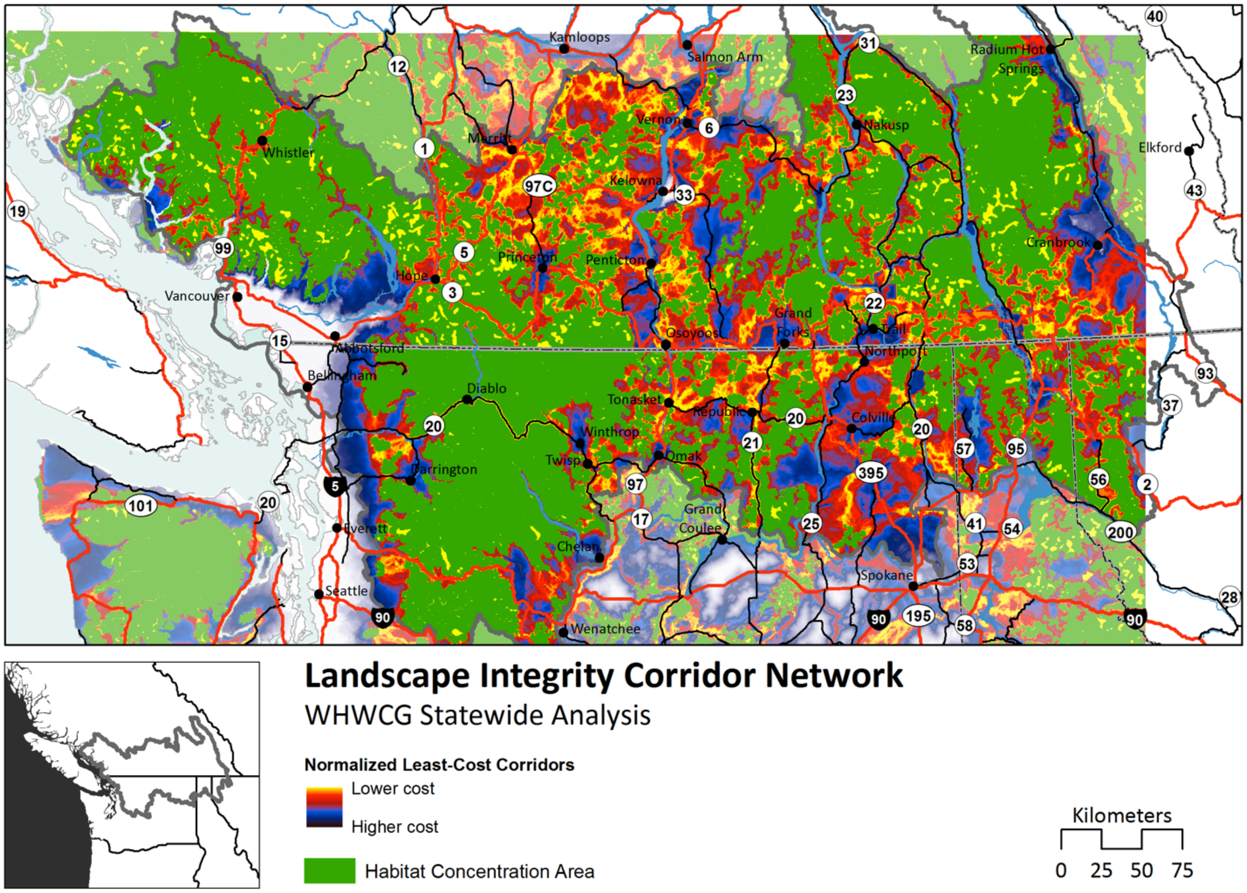
Appendix K.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

ii) Extent: Okanagan-Kettle Region



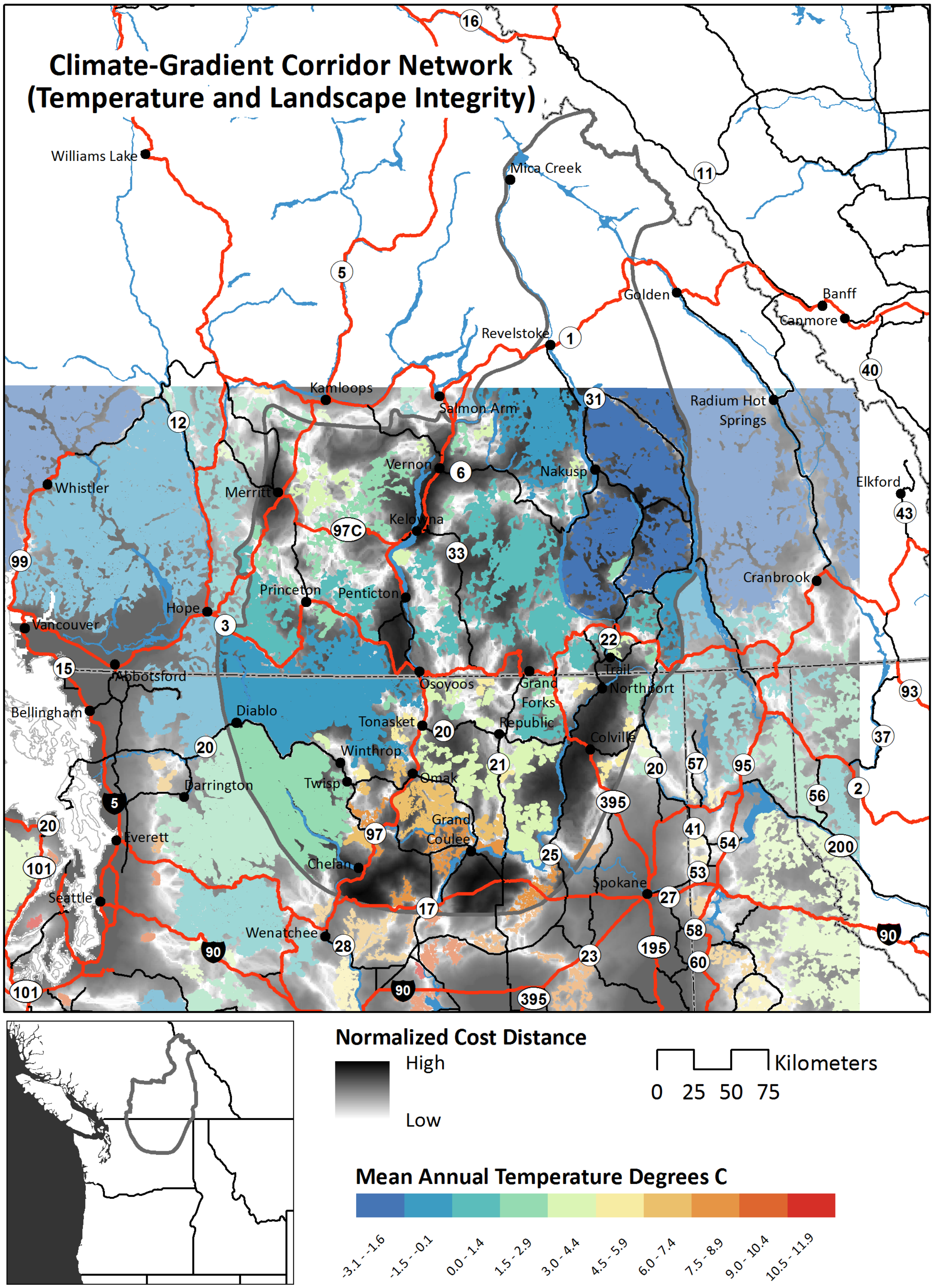
Appendix K.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

iii) Extent: Washington-British Columbia Transboundary Region



Appendix K.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

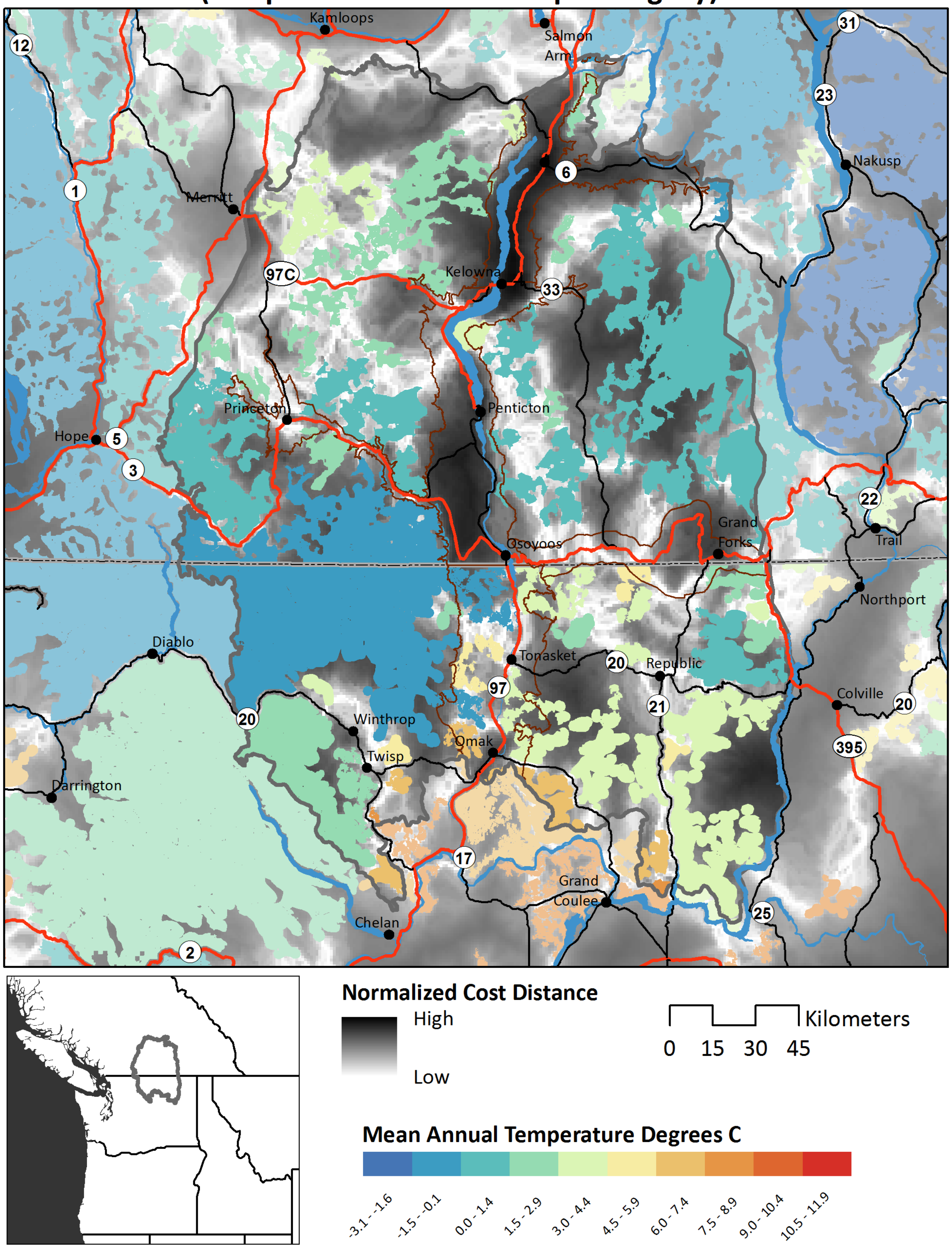
i) Extent: Okanagan Nation Territory



Appendix K.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

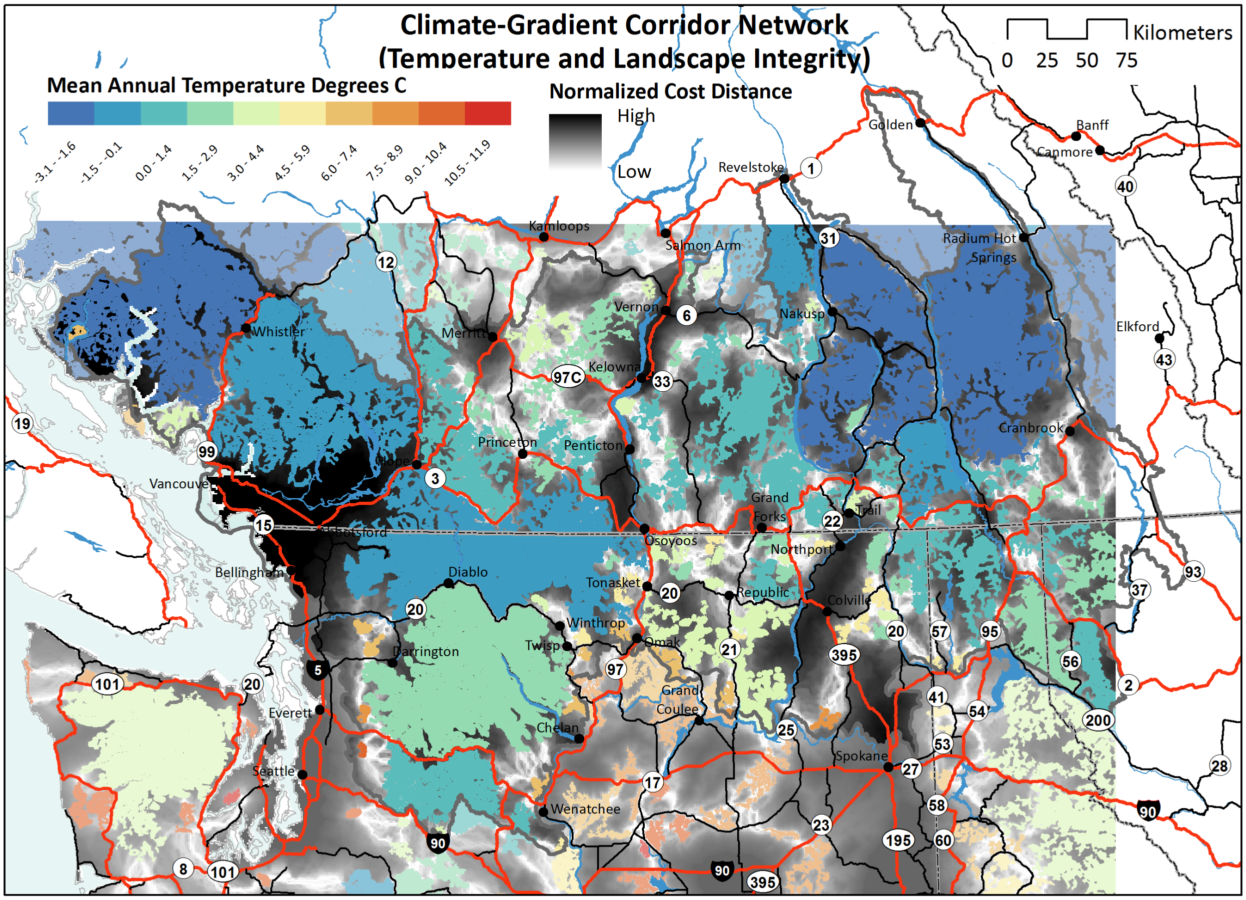
ii) Extent: Okanagan-Kettle Region

Climate-Gradient Corridor Network (Temperature and Landscape Integrity)



Appendix K.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

iii) Extent: Washington-British Columbia Transboundary Region



Appendix K.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary bull trout habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence bull trout habitat connectivity, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The bull trout conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to bull trout habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

Expert reviewers for the bull trout conceptual model included:

- Hillary Ward, BC FLNRO
- Dan Isaak, USFS Rocky Mountain Research Station

Key references used to create the bull trout conceptual model included:

Downs, C. C., Horan, D., Morgan-Harris, E., and R. Jakubowski. 2006. Spawning demographics and juvenile dispersal of an adfluvial bull trout population in Trestle Creek, Idaho. *North American Journal of Fisheries Management* 26:190-200.

Falke, J.A., Flitcroft, R.L., Dunham, J.B., McNyset, K.M., Hessburg, P.F., Reeves, G.H., and Marshall, C.T. 2014. Climate change and vulnerability of bull trout (Salvelinus confluentus) in a fire-prone landscape. *Canadian Journal of Fisheries and Aquatic Sciences* 72: 1–15.

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Monnot, L., Dunham, J.B., Salow, T., and P. Koetsier. 2008. Influences of body size and environmental factors on autumn downstream migration of bull trout in the Boise River, Idaho. *North American Journal of Fisheries Management* 28:231-240.

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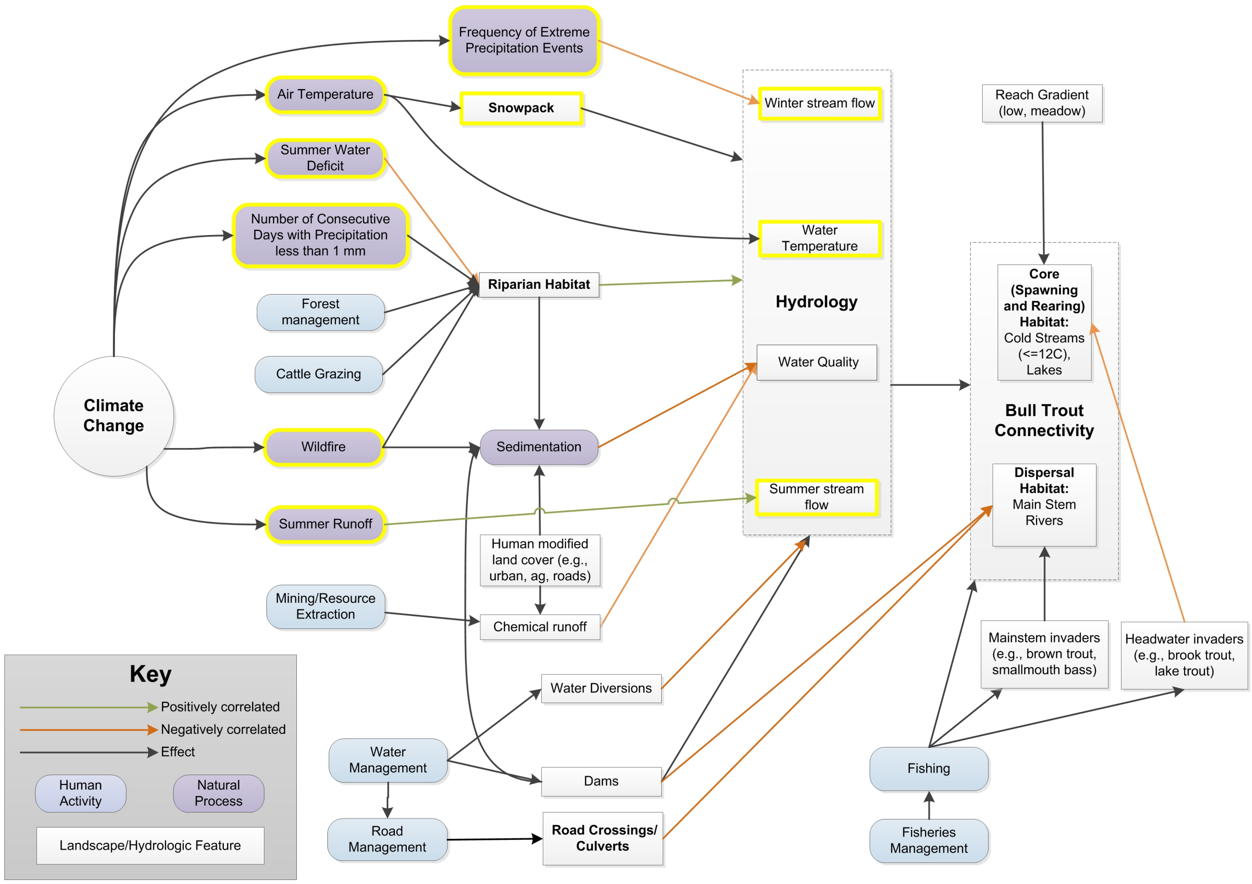
Wenger, S.J., Isaak, D.J., Luce, C.H., et al. 2011. Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. *Proceedings of the National Academy of Sciences* 108:14175–14180.

Appendix K.2. Conceptual model of bull trout habitat connectivity



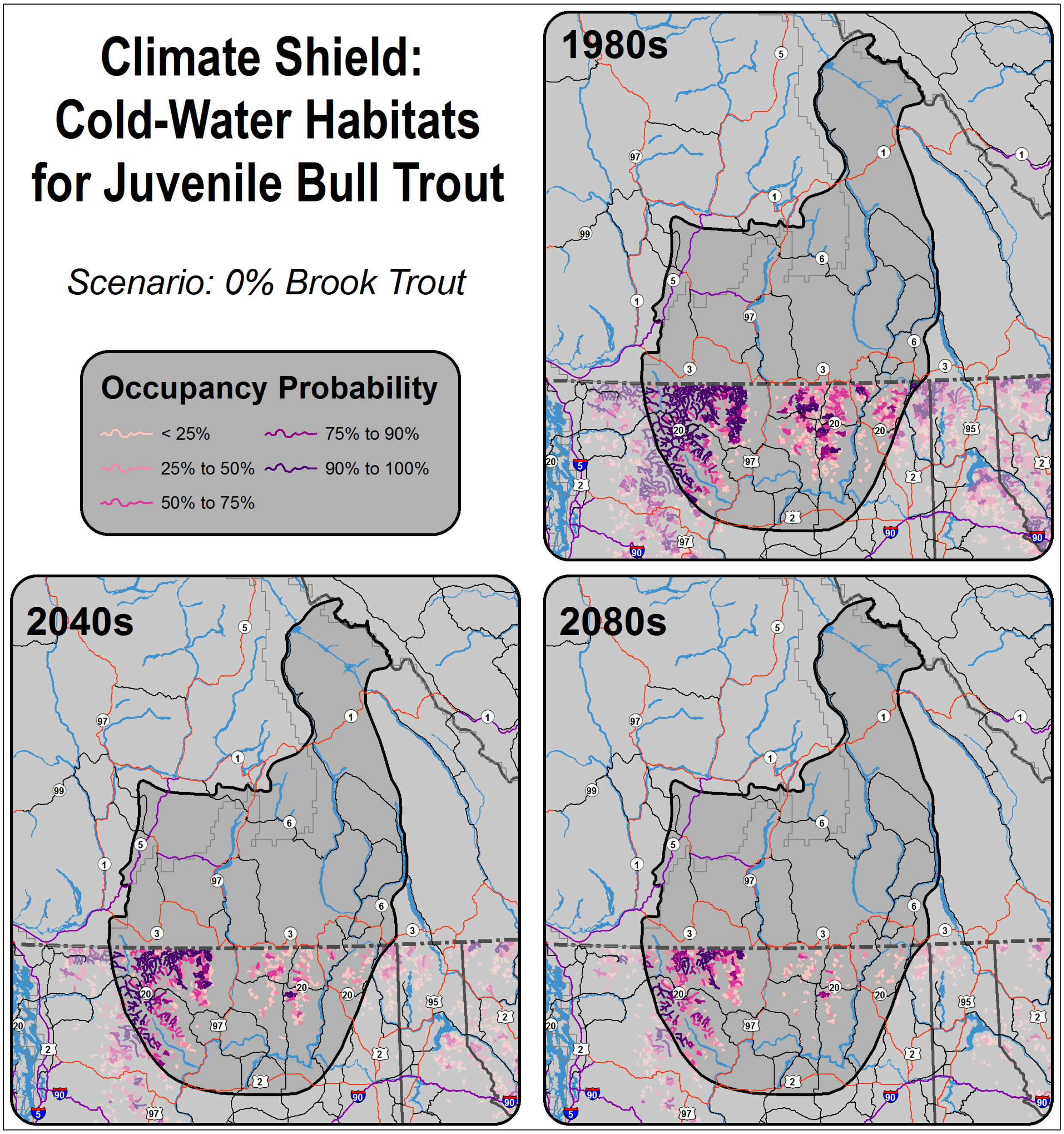
Appendix K.3. Projected Probability of Juvenile Bull Trout Occupancy

Projected changes in the probability of stream occupancy by juvenile bull trout are available for the 2040s (2030-2059) and 2080s (2070-2099).[12,vii] Streams are color coded based on the estimated probability of juvenile bull trout occupancy, where light pink stream shading indicates areas within the historical bull trout range where juvenile bull trout are projected to have a low probability of occupancy, and dark purple shading indicates areas where juvenile bull trout are projected to have a high probability of occupancy. Brook trout presence, often associated with declines in bull trout, was assumed to be 0% for these projections.

[vii] Projections are based on an A1B (moderate) carbon emissions scenario using an ensemble of ten global climate models that best predicted historic climate conditions during the 20th century in the northwestern US. Projections are only available for the US. Projected future changes in stream temperatures were based on similar projected changes in August air temperature and stream discharge, and accounted for differential warming of streams by using historical temperatures to scale temperature increases so that cold streams warm less than warm streams. Data available at: http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.html

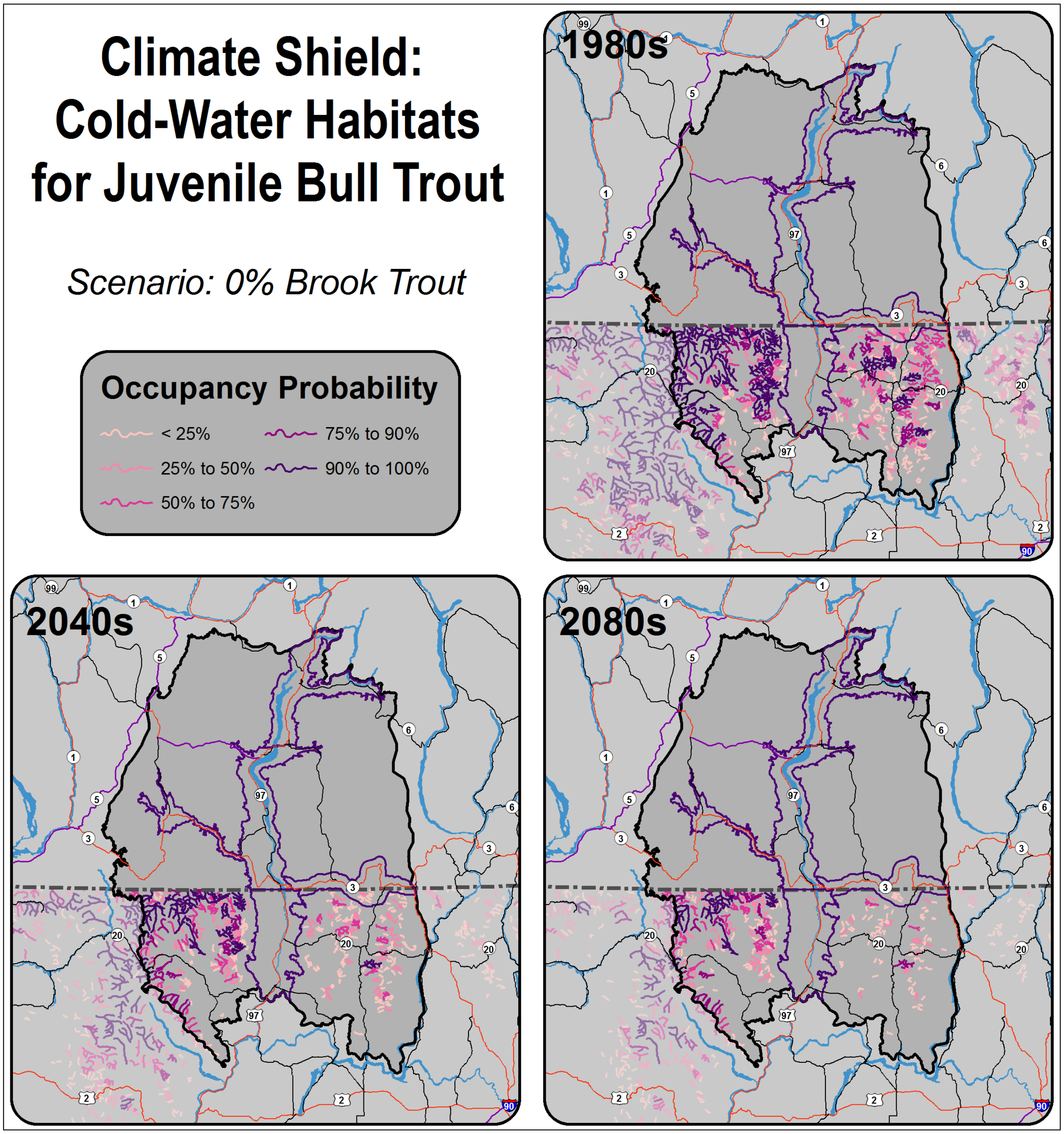
Appendix K.3. Probability of Juvenile Bull Trout Occupancy

i) Extent: Okanagan Nation Territory



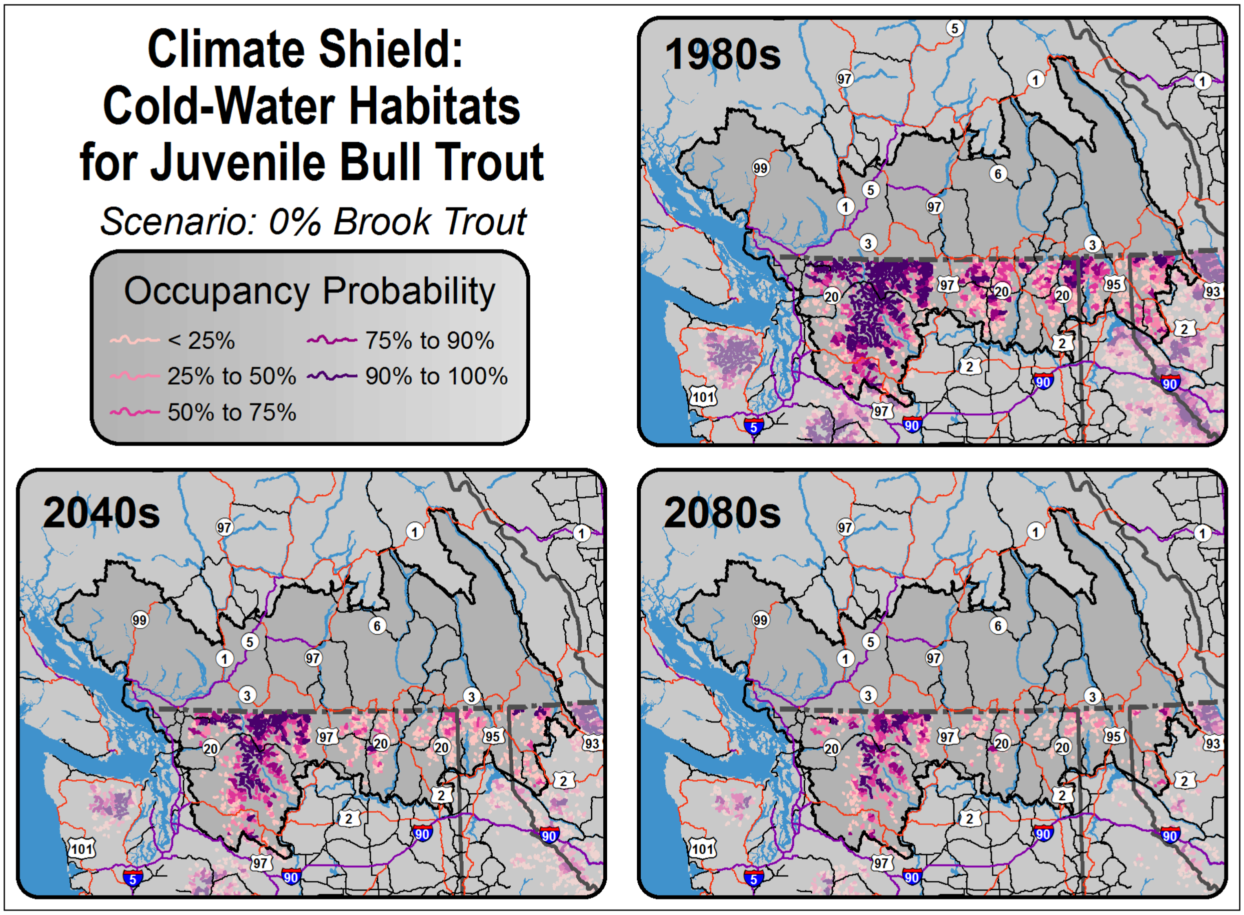
Appendix K.3. Probability of Juvenile Bull Trout Occupancy

ii) Extent: Okanagan-Kettle Region



Appendix K.3. Probability of Juvenile Bull Trout Occupancy

iii) Extent: Washington-British Columbia Transboundary Region



Appendix K.4. Projected Changes in Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on bull trout habitat connectivity. Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[9] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[10] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Stream Temperature.**[14,viii] This map shows historical (1993-2011) and projected future stream temperatures within the historical range of bull trout. Historical and projected stream temperatures are depicted by the light pink to maroon shading.

b) **Spring (April 1st) Snowpack.**[ix] This map snows the percent change in snow water equivalent (SWE) on April 1st. April 1st is the approximate current timing of peak annual snowpack in Northwest mountains. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

c) **Maximum 24-hour Precipitation.**[ix] This map shows projected change, in percent, in the maximum 24-hour precipitation amount. Projected changes in maximum 24-hour precipitation amounts are depicted by the yellow to green shading.

d) **Total Spring Runoff.**[ix] This map shows projected change, in percent, in spring (March-May) runoff. This includes any overland water flows in addition to subsurface runoff in shallow groundwater. Projected changes in spring runoff are depicted by the yellow to green shading.

e) **Total Summer Runoff.**[ix] This map shows projected change, in percent, in summer (July-September) runoff. This includes any overland water flows in addition to subsurface runoff in shallow groundwater. Projected changes in spring runoff are depicted by the teal to brown shading.

f) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile).[x,xi] This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.

[viii] Stream temperature projections are evaluated for the 2040s (2030-2059) and 2080s (2070-2099), based on global climate model ensemble averages using the A1B (moderate) emissions scenario, and do not extend into British Columbia. Data is available at: http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

[ix] Projections are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5).

[x] 'Days with High Fire Risk' is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5)) using the RCP 8.5 (high) emissions scenario.

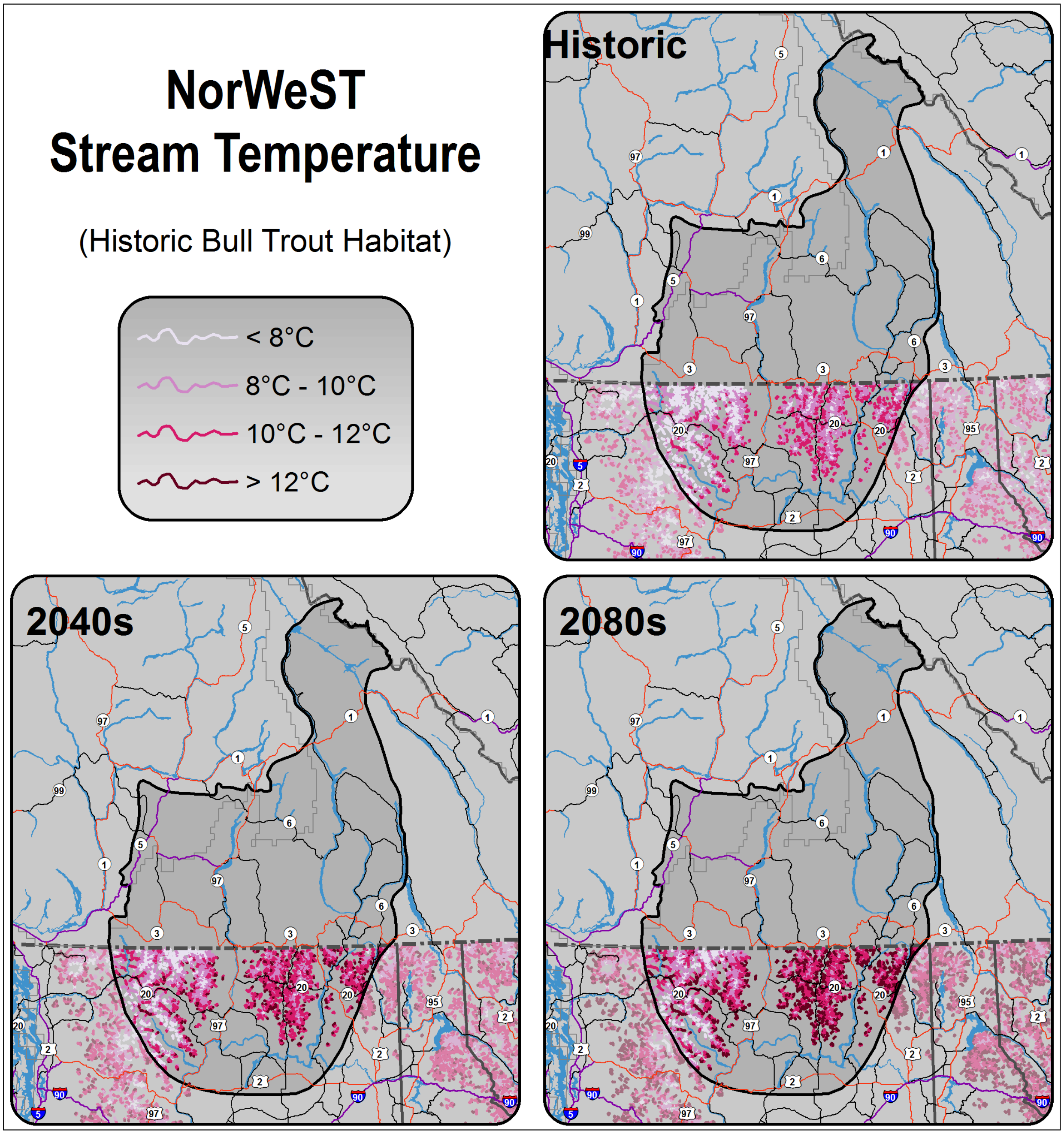
[xi] Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology* 33: 121-131.

g) **Dry Spell Duration.**[ix] This map shows the projected change, in percent, in the maximum number of consecutive days with less than 1 mm of precipitation.[ix] Projected change in dry spell duration is depicted by the brown to green shading.

h) **Water Deficit, July-September.**[ix] This map shows the projected change, in percent, in water deficit. Water deficit is defined as the difference between potential evapotranspiration (PET) and actual evapotranspiration (AET), PET - AET. A positive value for PET – AET means that atmospheric demand for water is greater than the actual supply available.

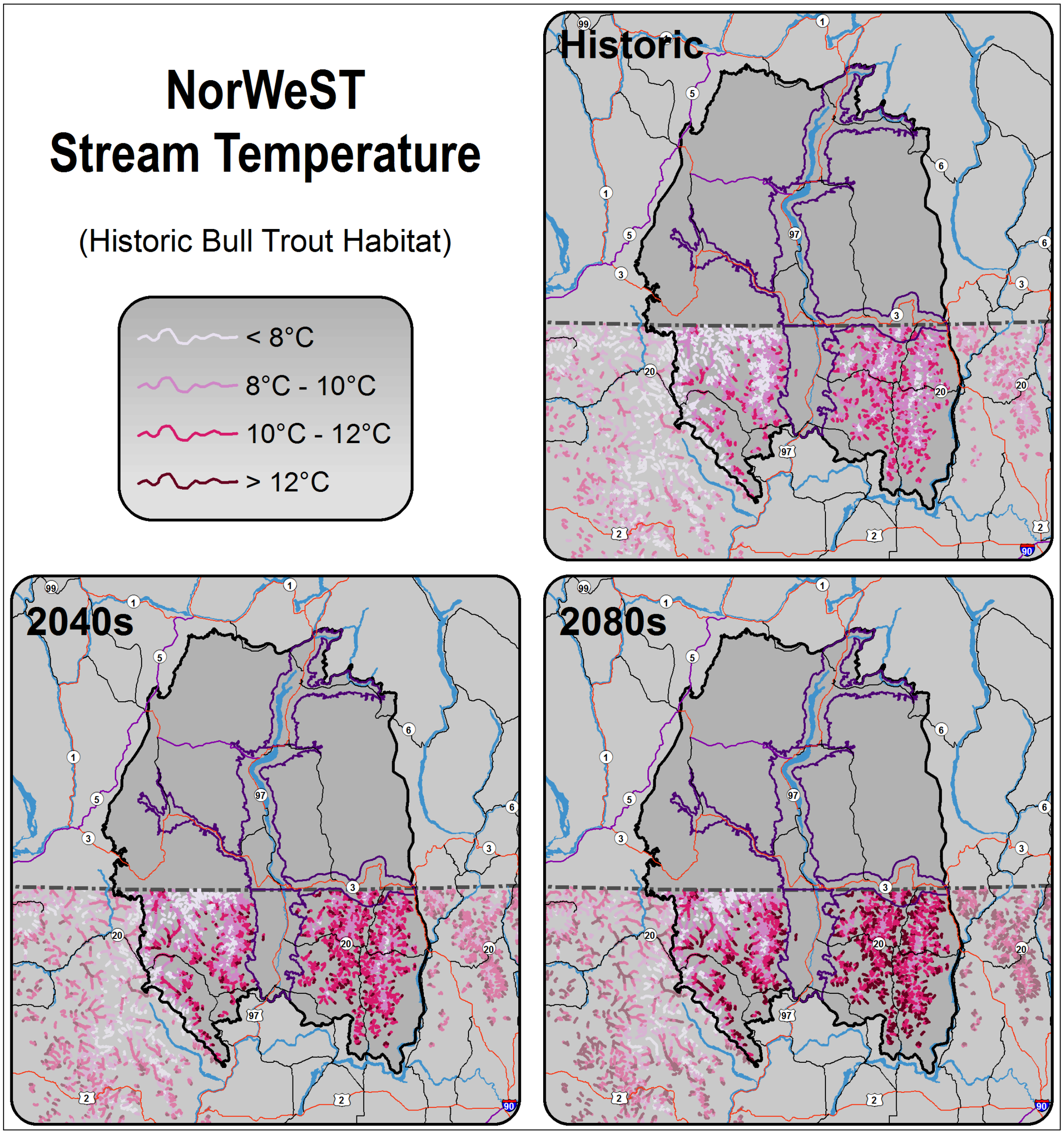
Appendix K.4a. Stream Temperature

i) Extent: Okanagan Nation Territory



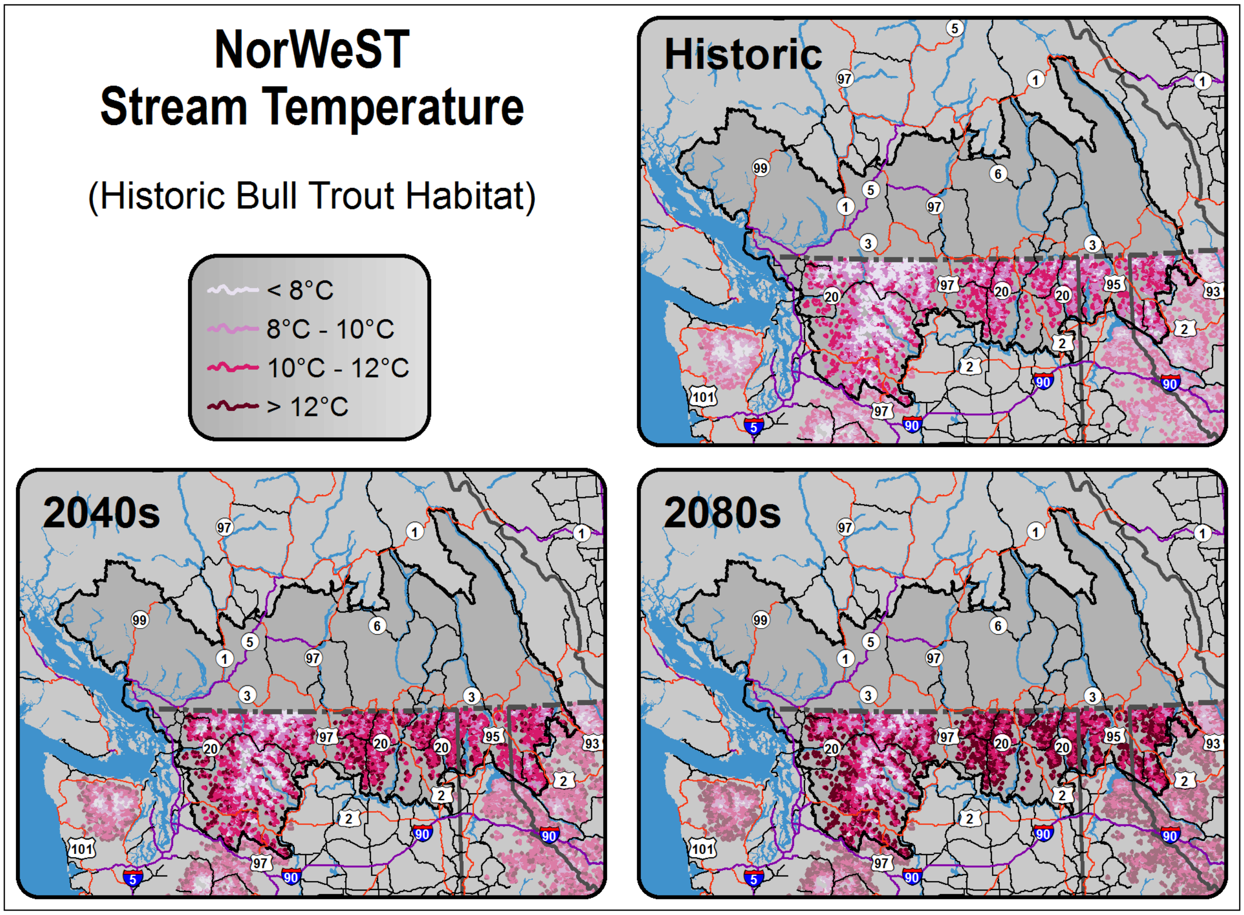
Appendix K.4a. Stream Temperature

ii) Extent: Okanagan-Kettle Region



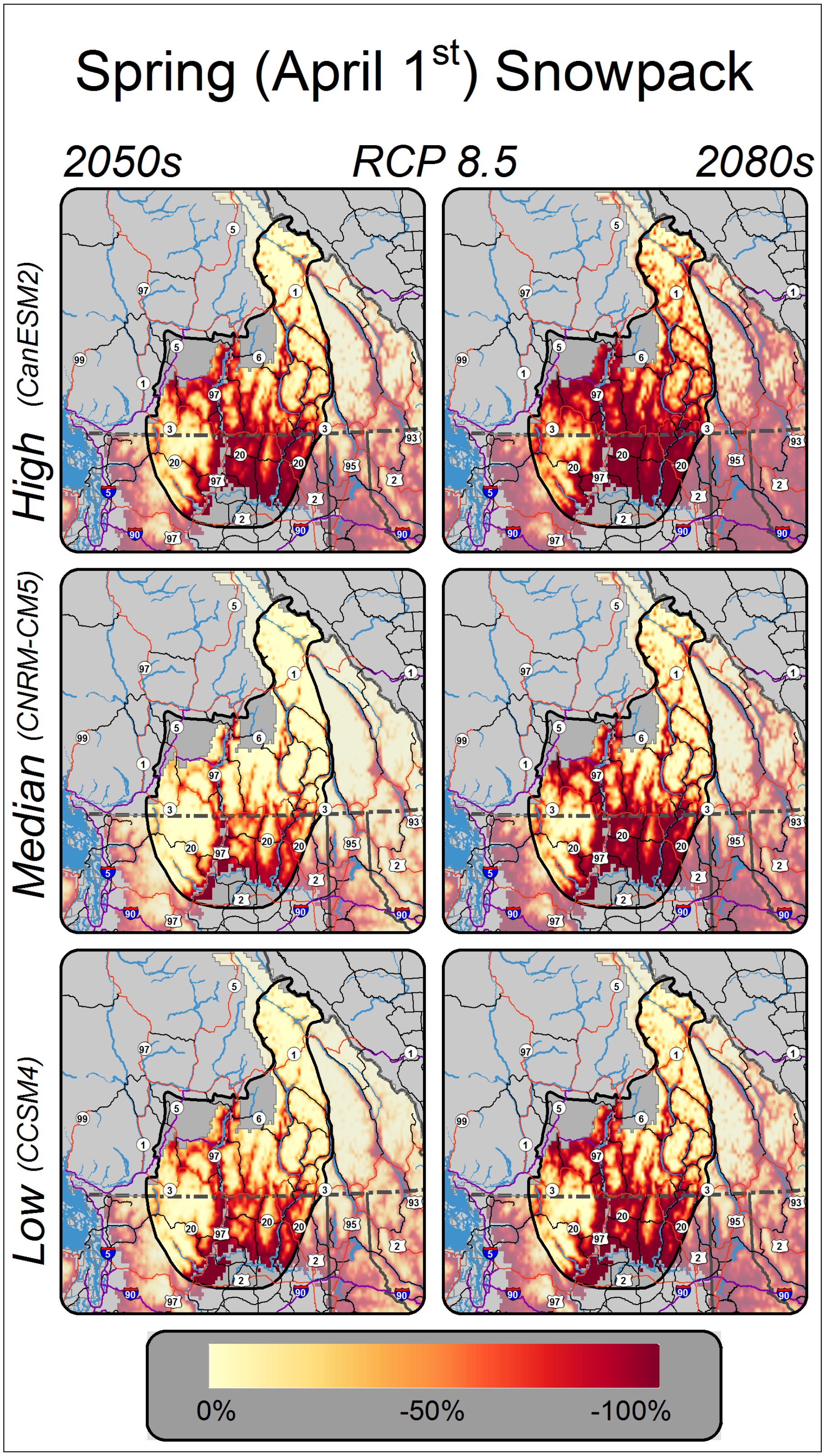
Appendix K.4a. Stream Temperature

iii) Extent: Washington-British Columbia Transboundary Region



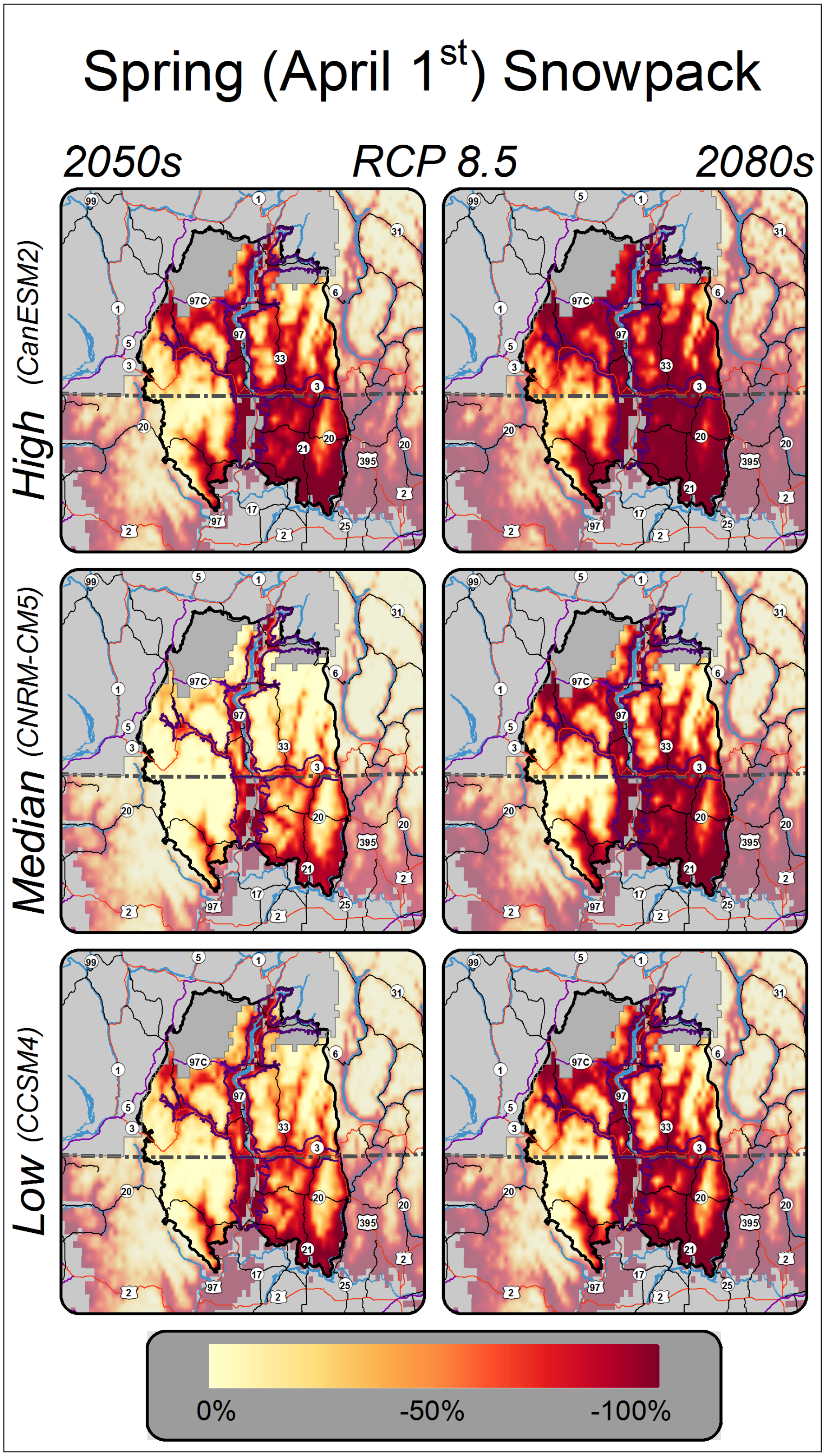
Appendix K.4b. Spring (April 1st) Snowpack

i) Extent: Okanagan Nation Territory



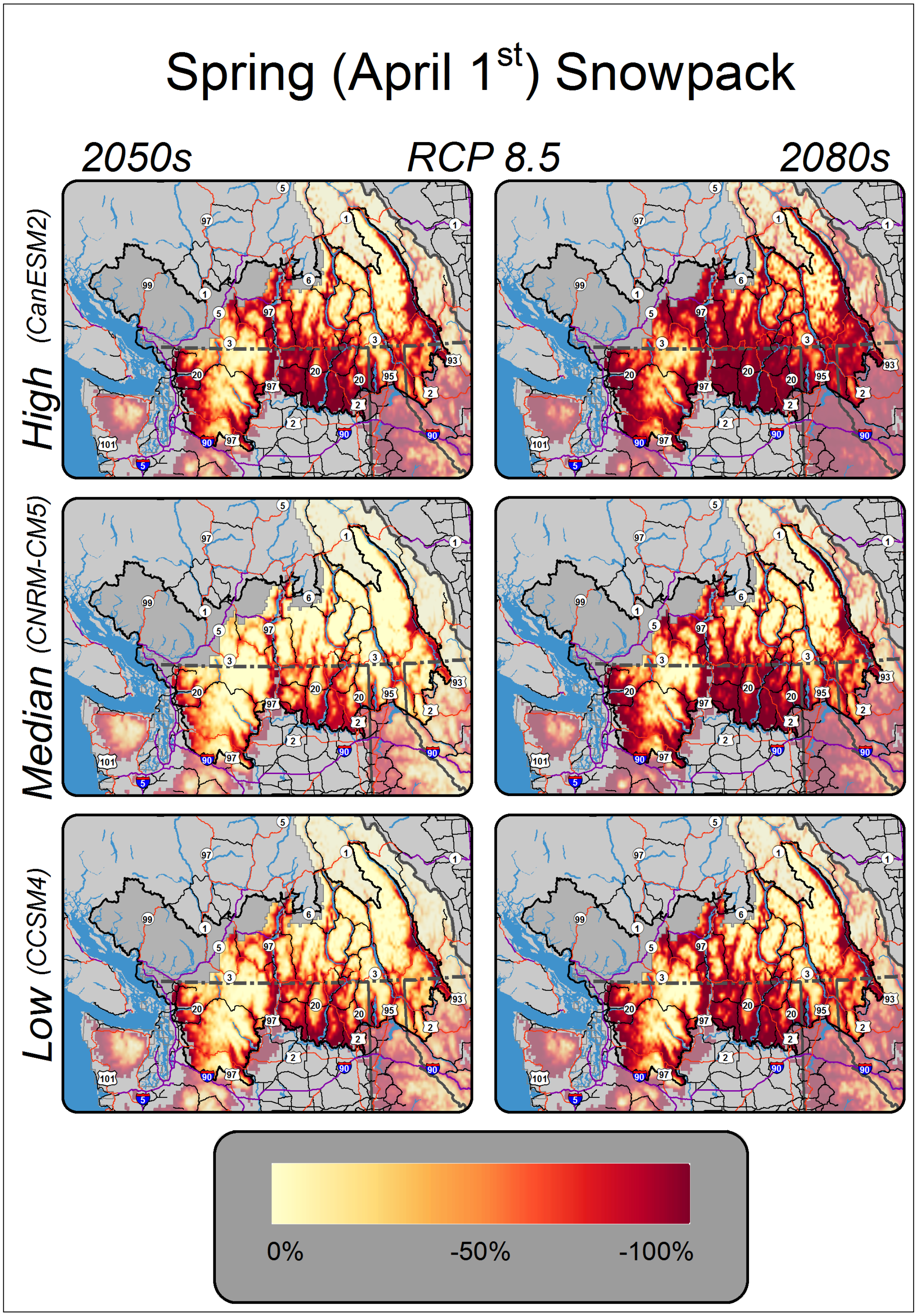
Appendix K.4b. Spring (April 1st) Snowpack

ii) Extent: Okanagan-Kettle Region



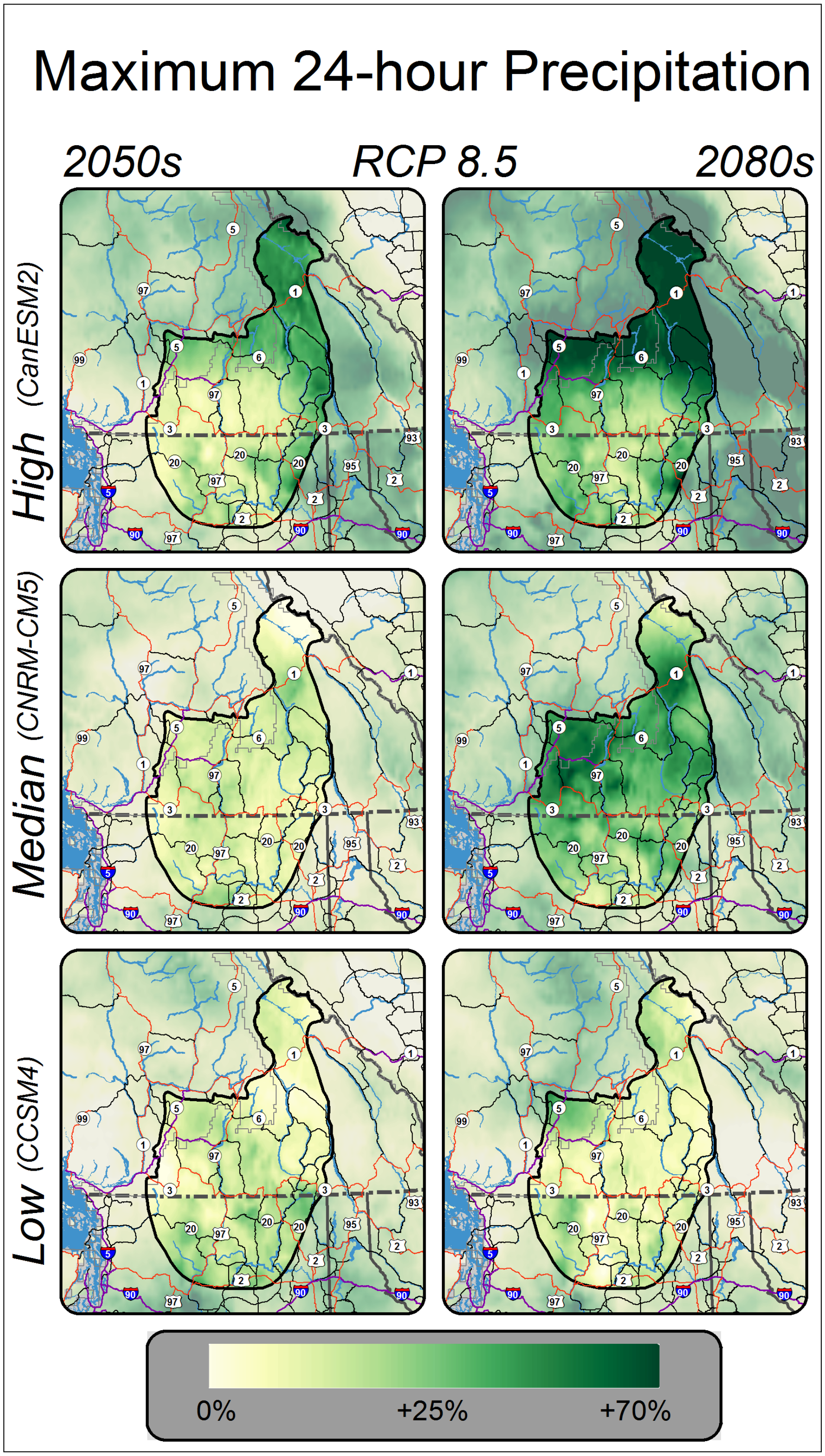
Appendix K.4b. Spring (April 1st) Snowpack

iii) Extent: Washington-British Columbia Transboundary Region



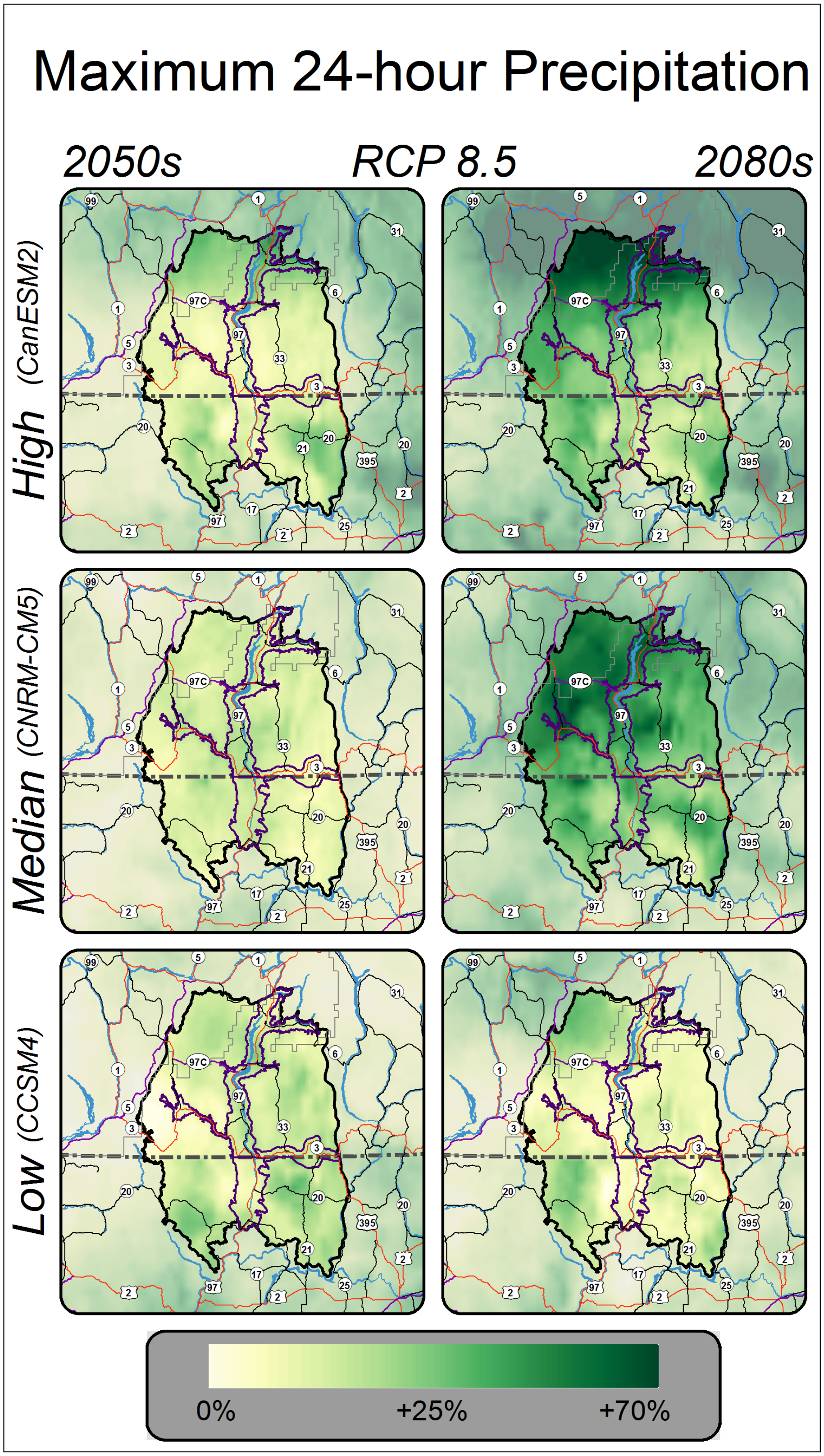
Appendix K.4c. Maximum 24-hour Precipitation

i) Extent: Okanagan Nation Territory



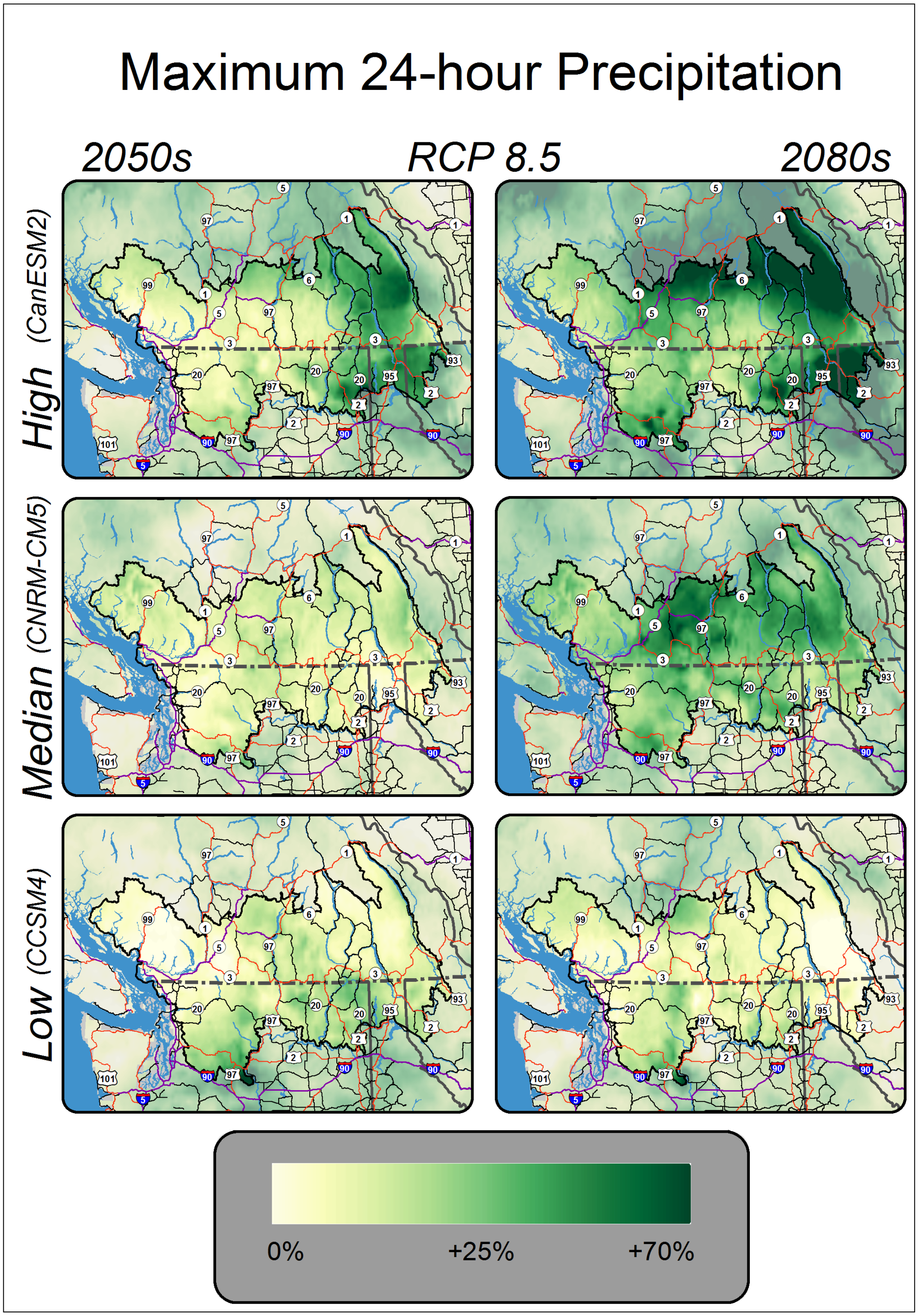
Appendix K.4c. Maximum 24-hour Precipitation

ii) Extent: Okanagan-Kettle Region



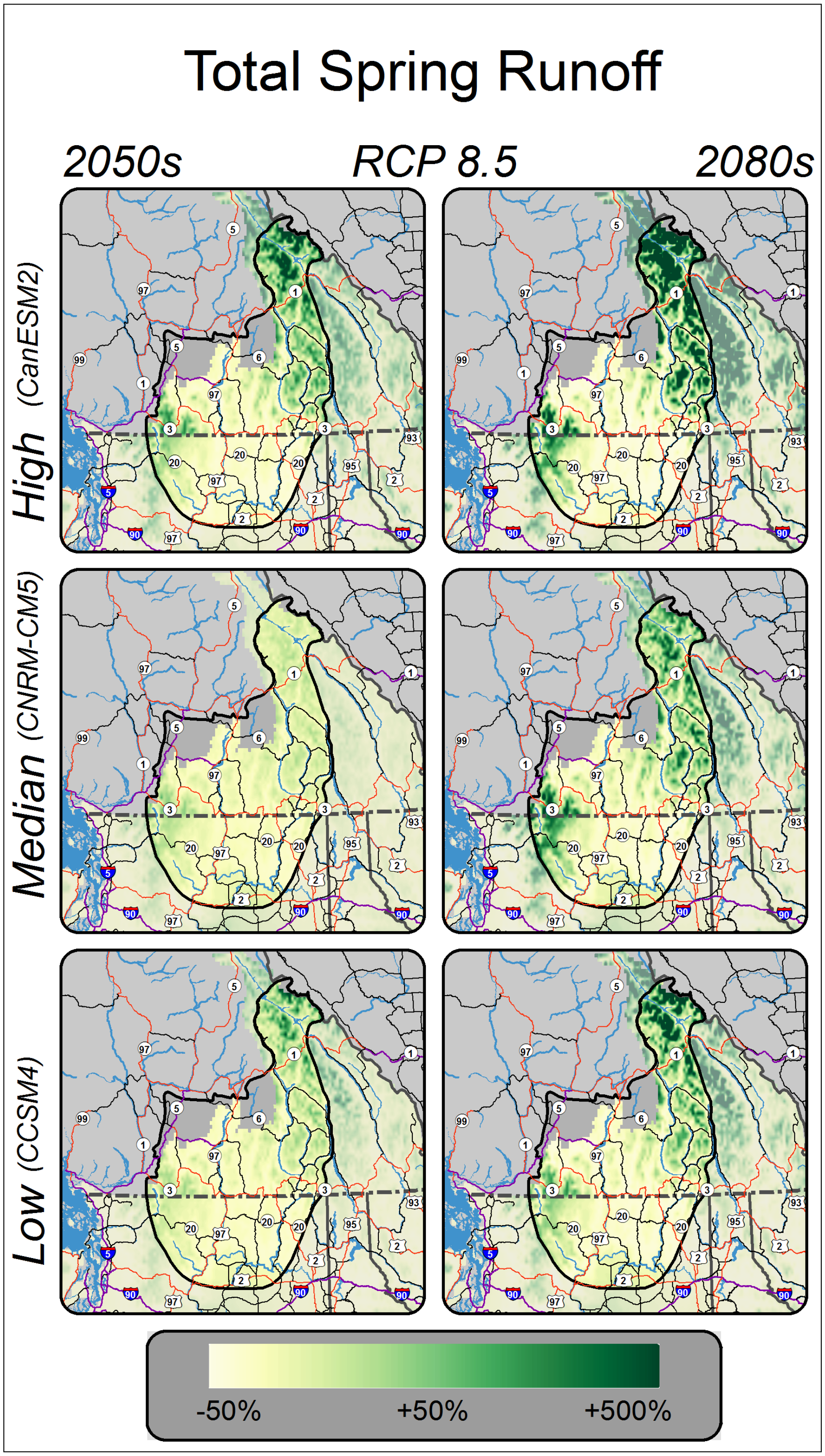
Appendix K.4c. Maximum 24-hour Precipitation

iii) Extent: Washington-British Columbia Transboundary Region



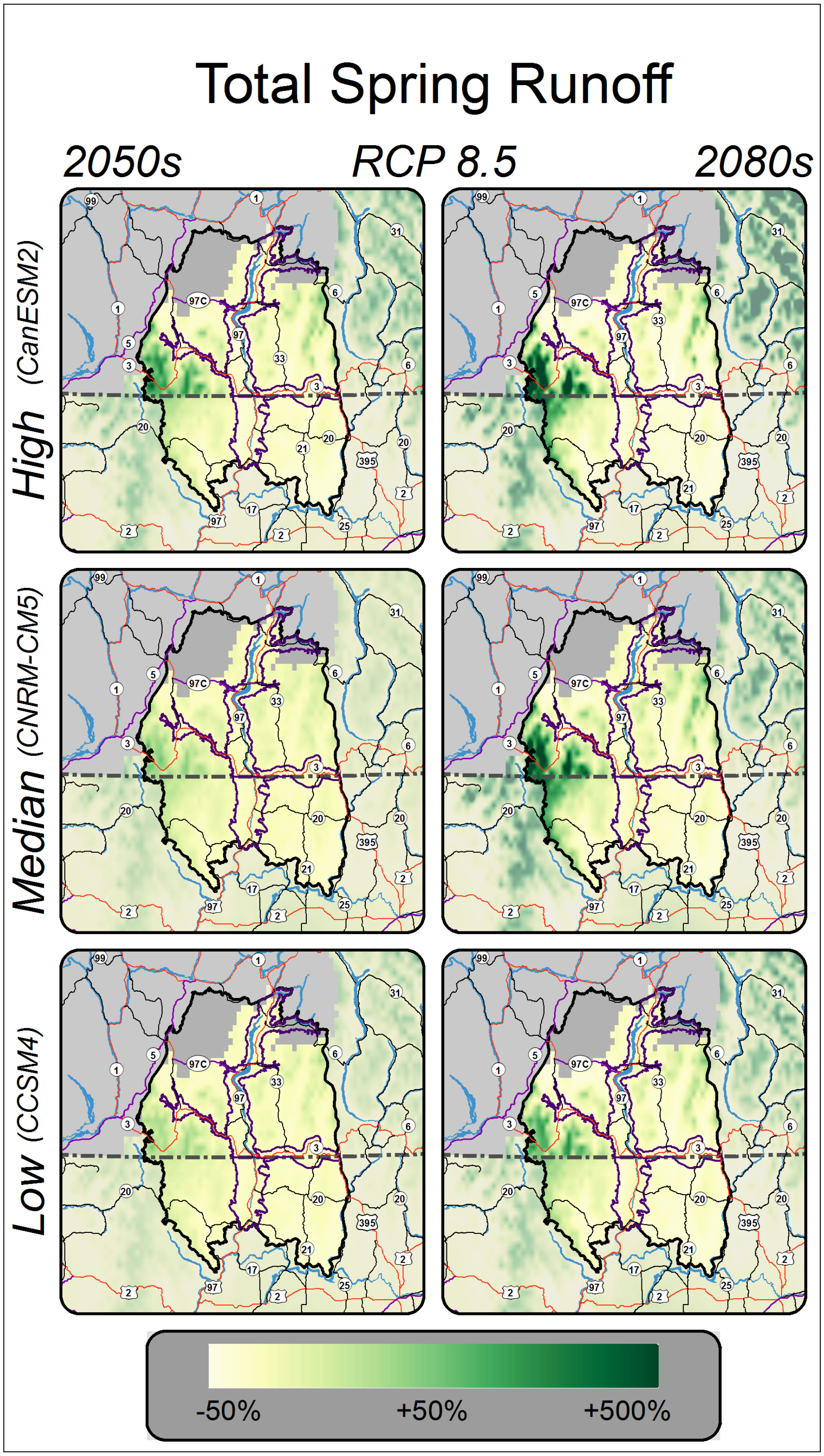
Appendix K.4d. Total Spring Runoff

i) Extent: Okanagan Nation Territory



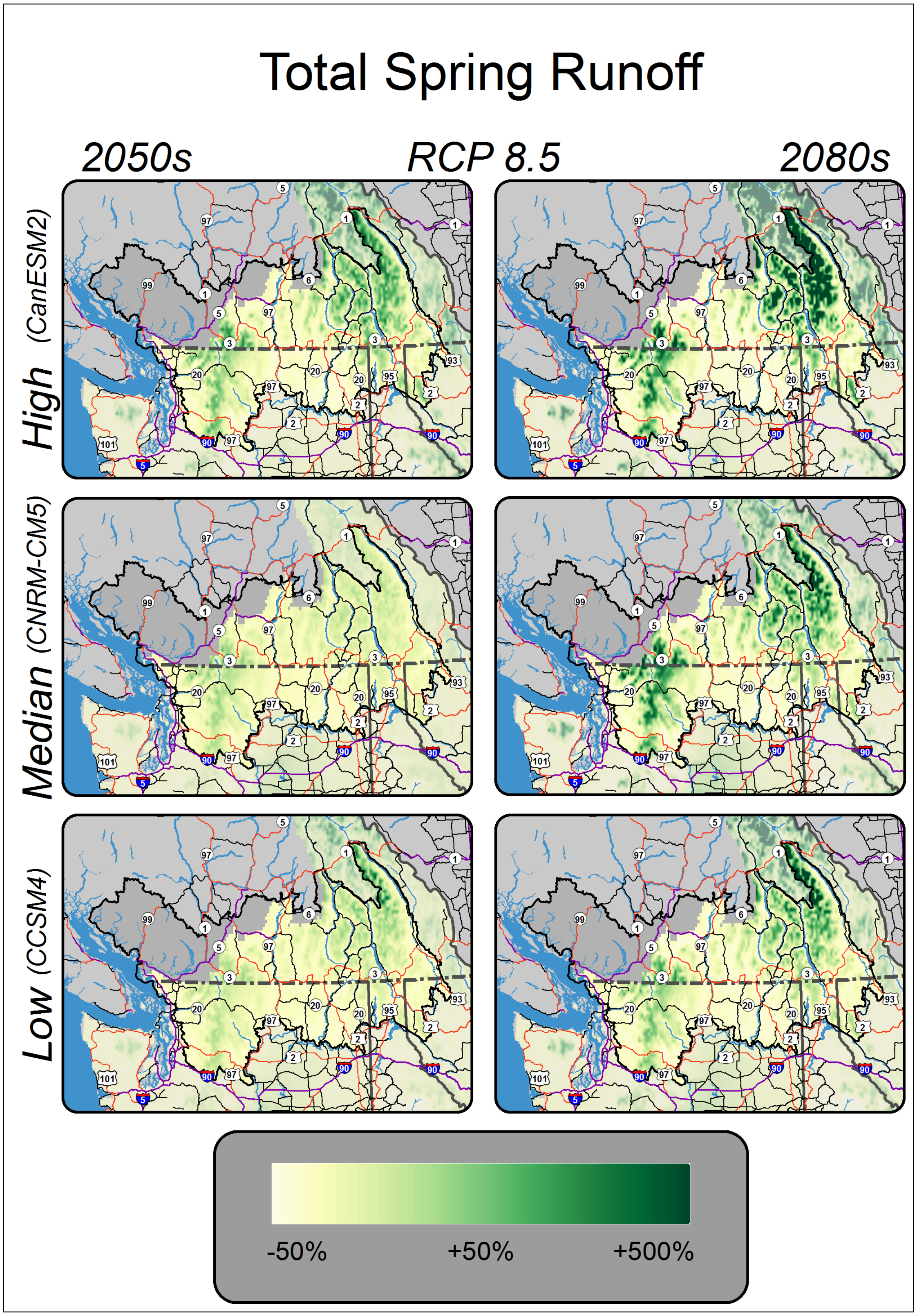
Appendix K.4d. Total Spring Runoff

ii) Extent: Okanagan-Kettle Region



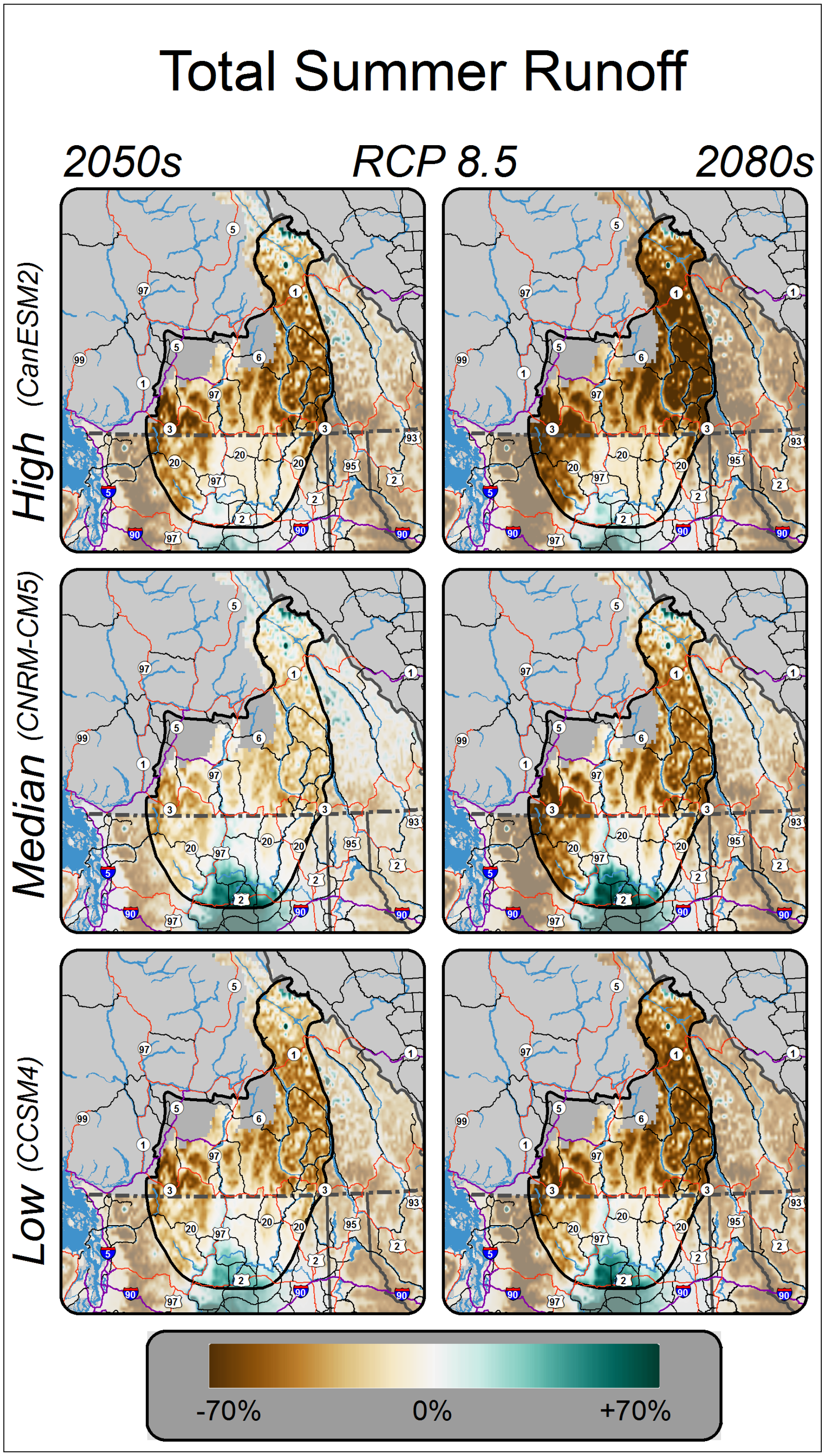
Appendix K.4d. Total Spring Runoff

iii) Extent: Washington-British Columbia Transboundary Region



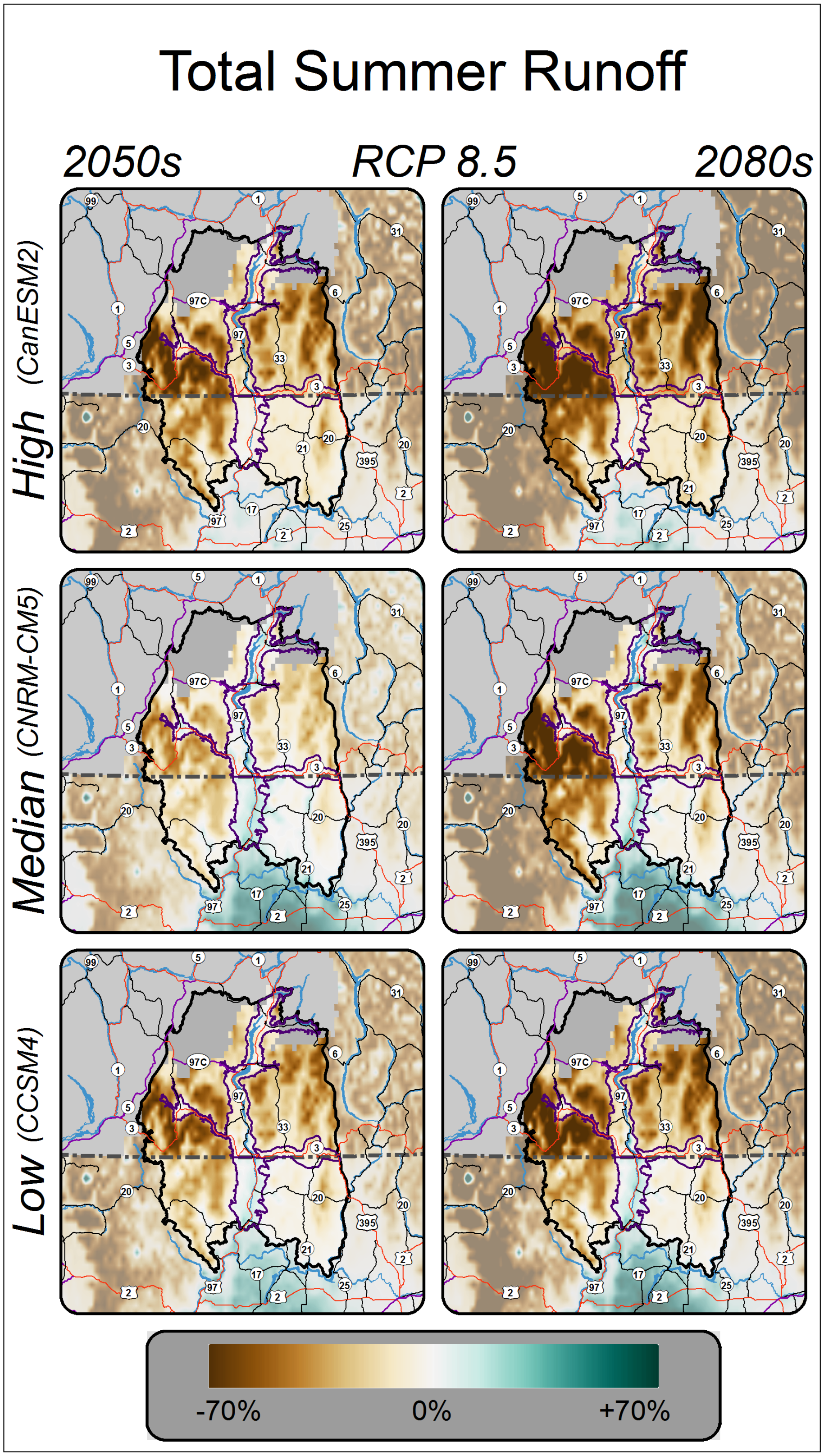
Appendix K.4e. Total Summer Runoff

i) Extent: Okanagan Nation Territory



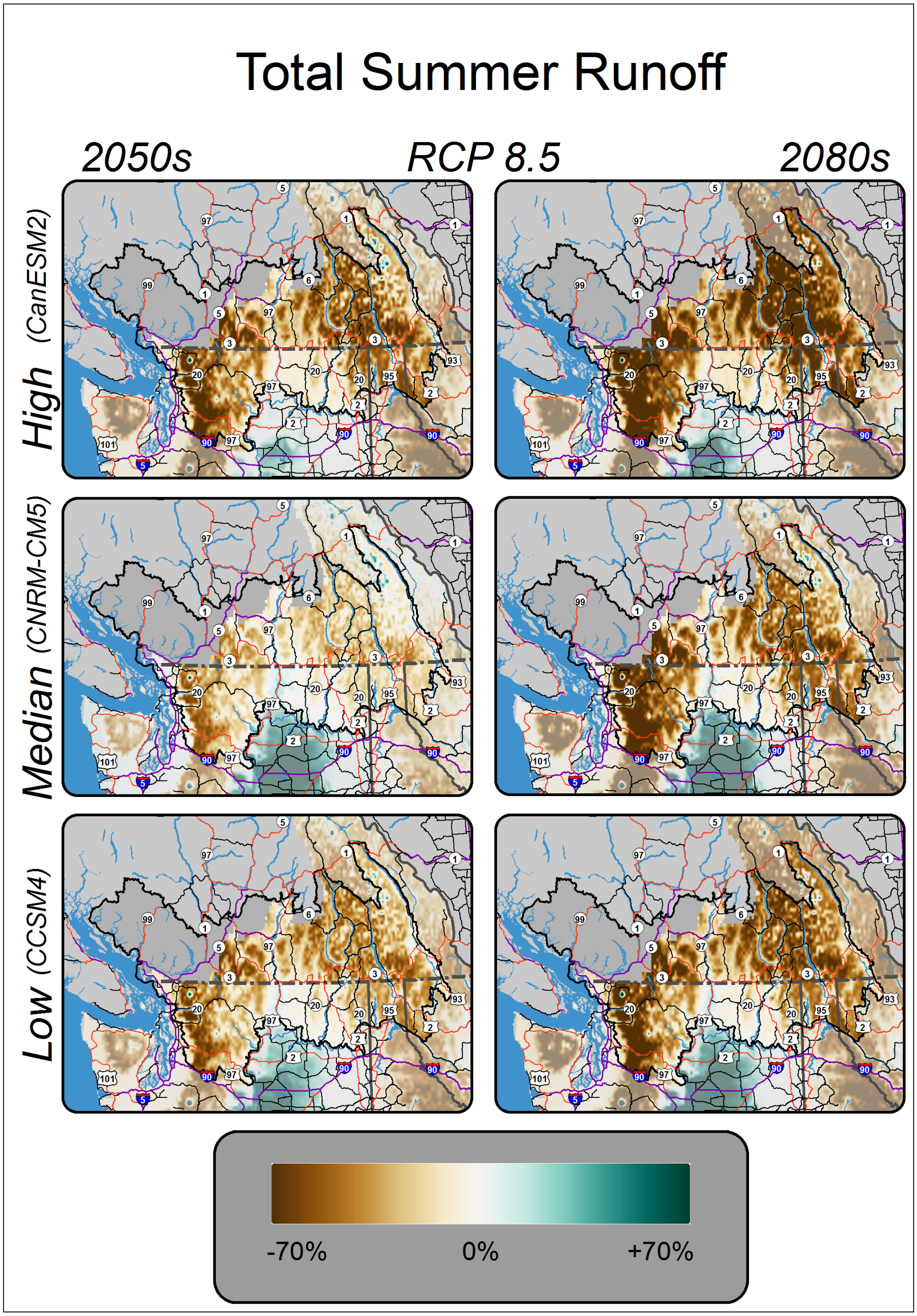
Appendix K.4e. Total Summer Runoff

ii) Extent: Okanagan-Kettle Region



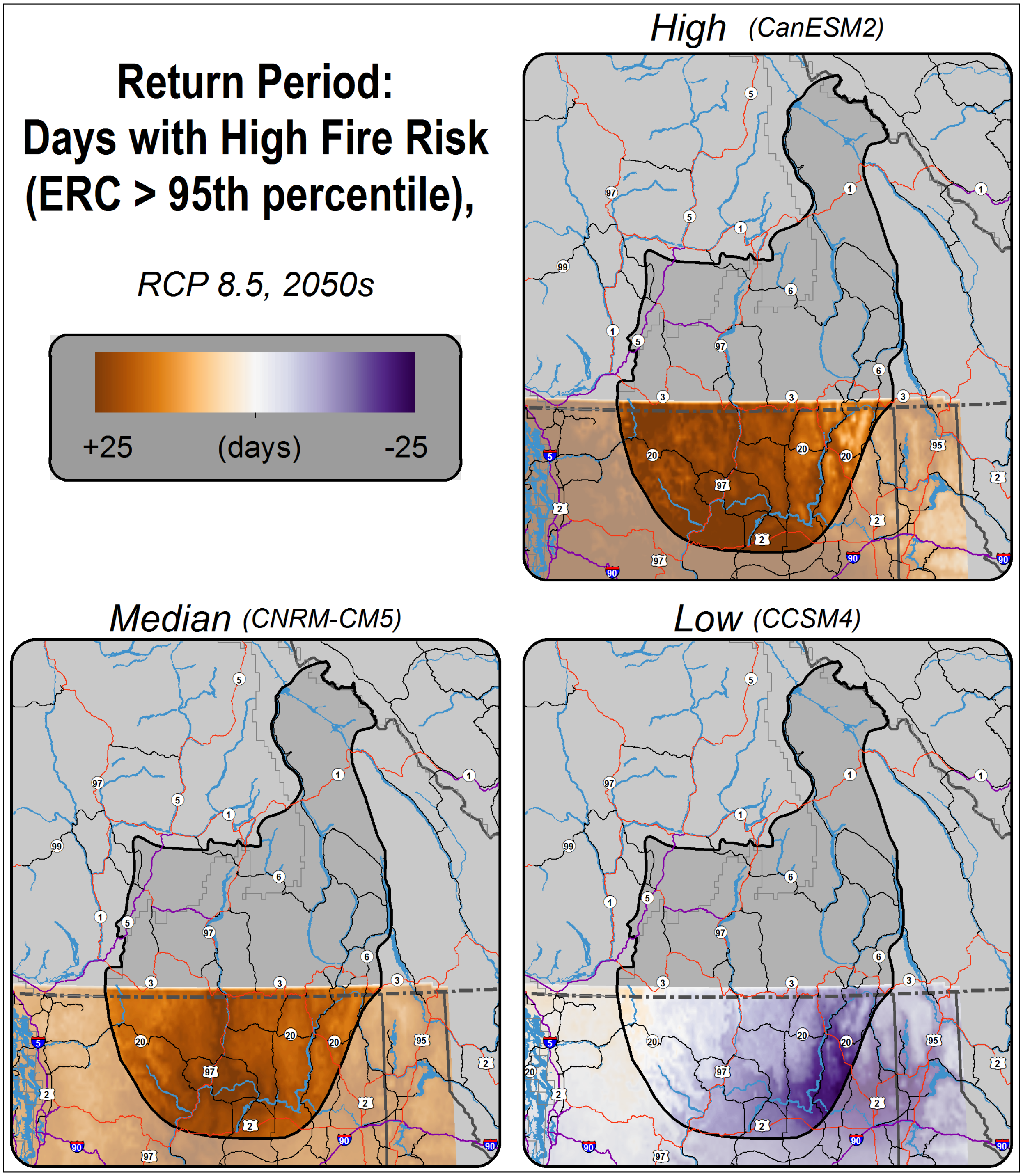
Appendix K.4e. Total Summer Runoff

iii) Extent: Washington-British Columbia Transboundary Region



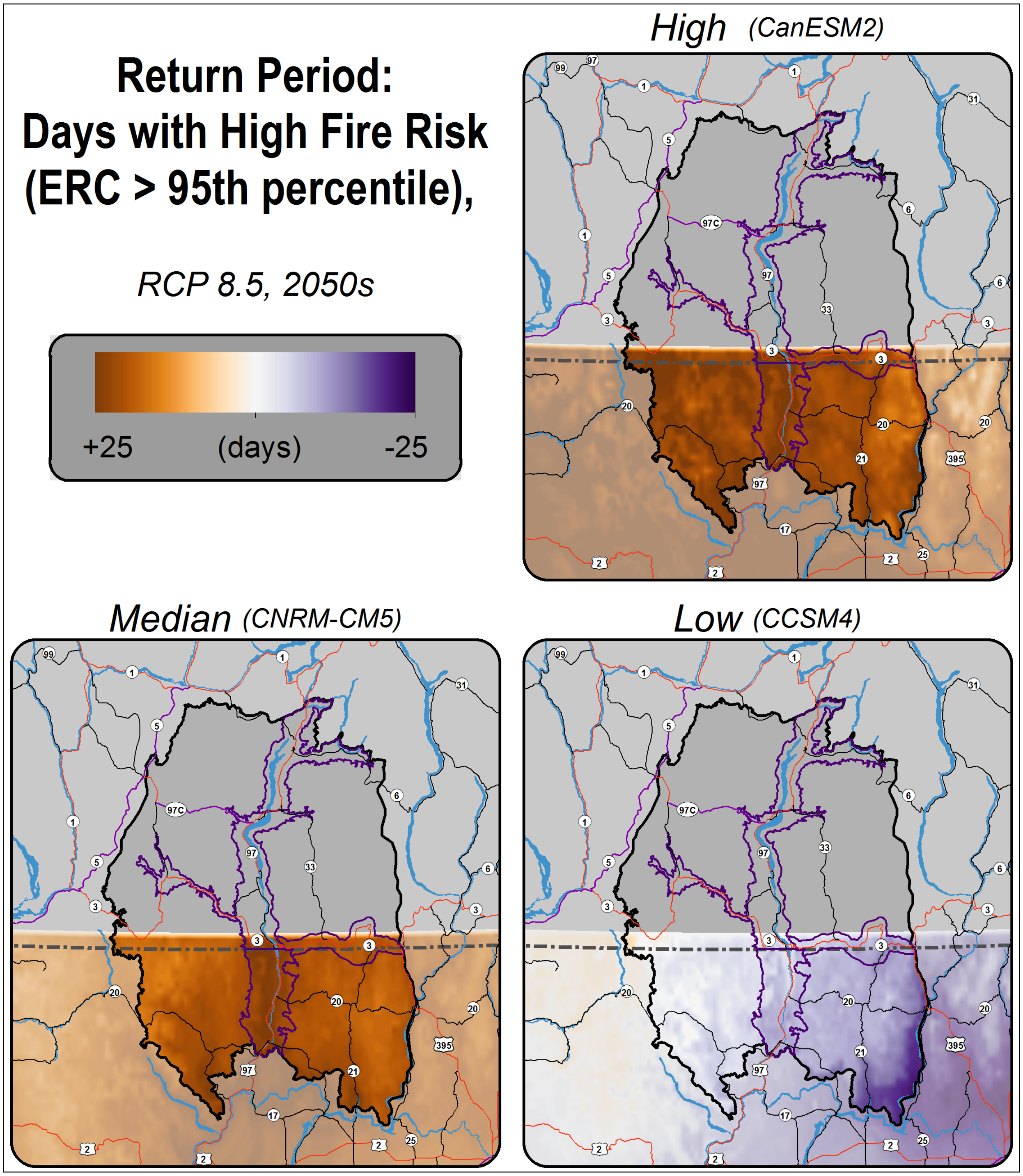
Appendix K.4f. Days with High Fire Risk

i) Extent: Okanagan Nation Territory



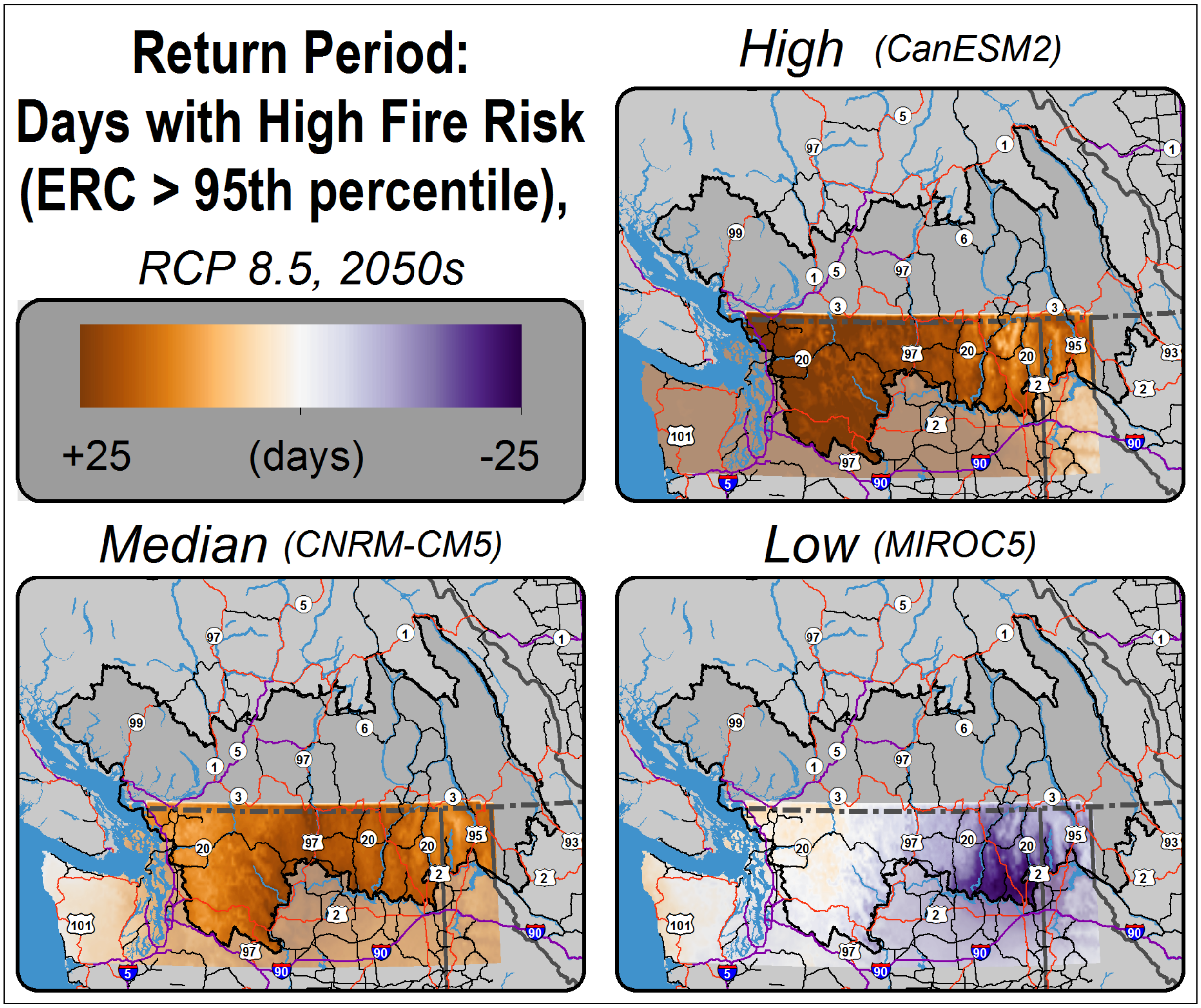
Appendix K.4f. Days with High Fire Risk

ii) Extent: Okanagan-Kettle Region



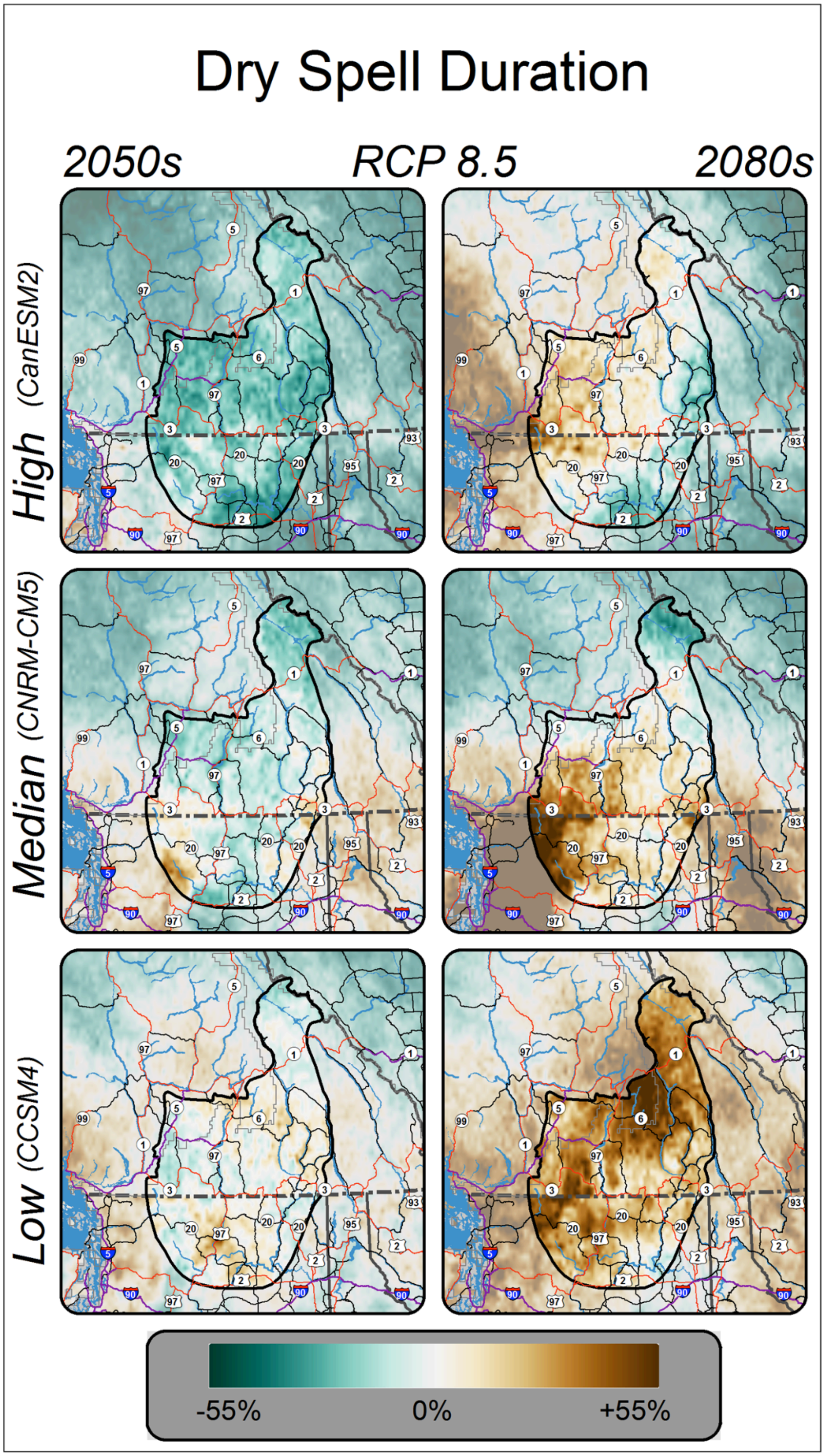
Appendix K.4f. Days with High Fire Risk

iii) Extent: Washington-British Columbia Transboundary Region



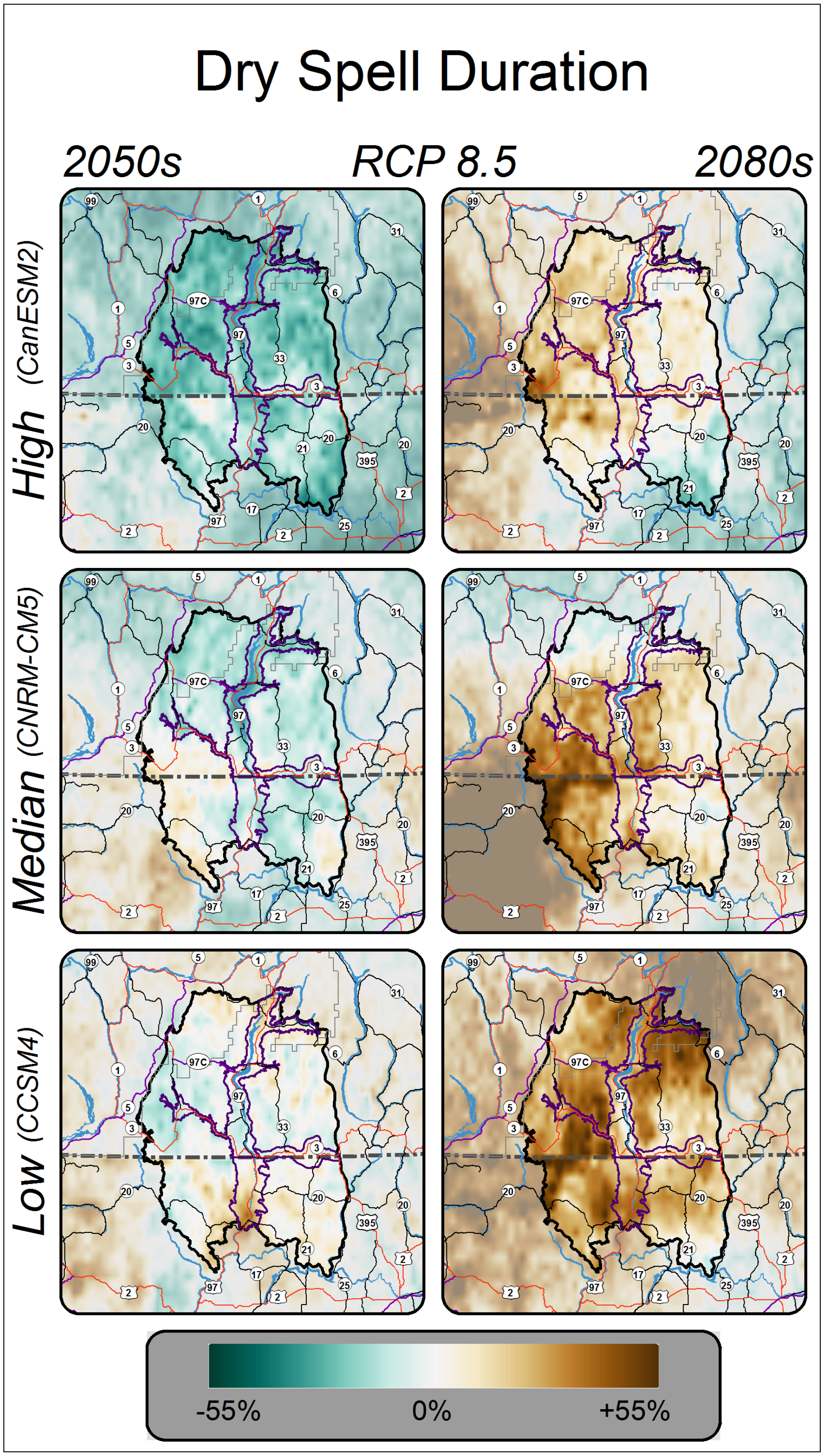
Appendix K.4g. Dry Spell Duration

i) Extent: Okanagan Nation Territory



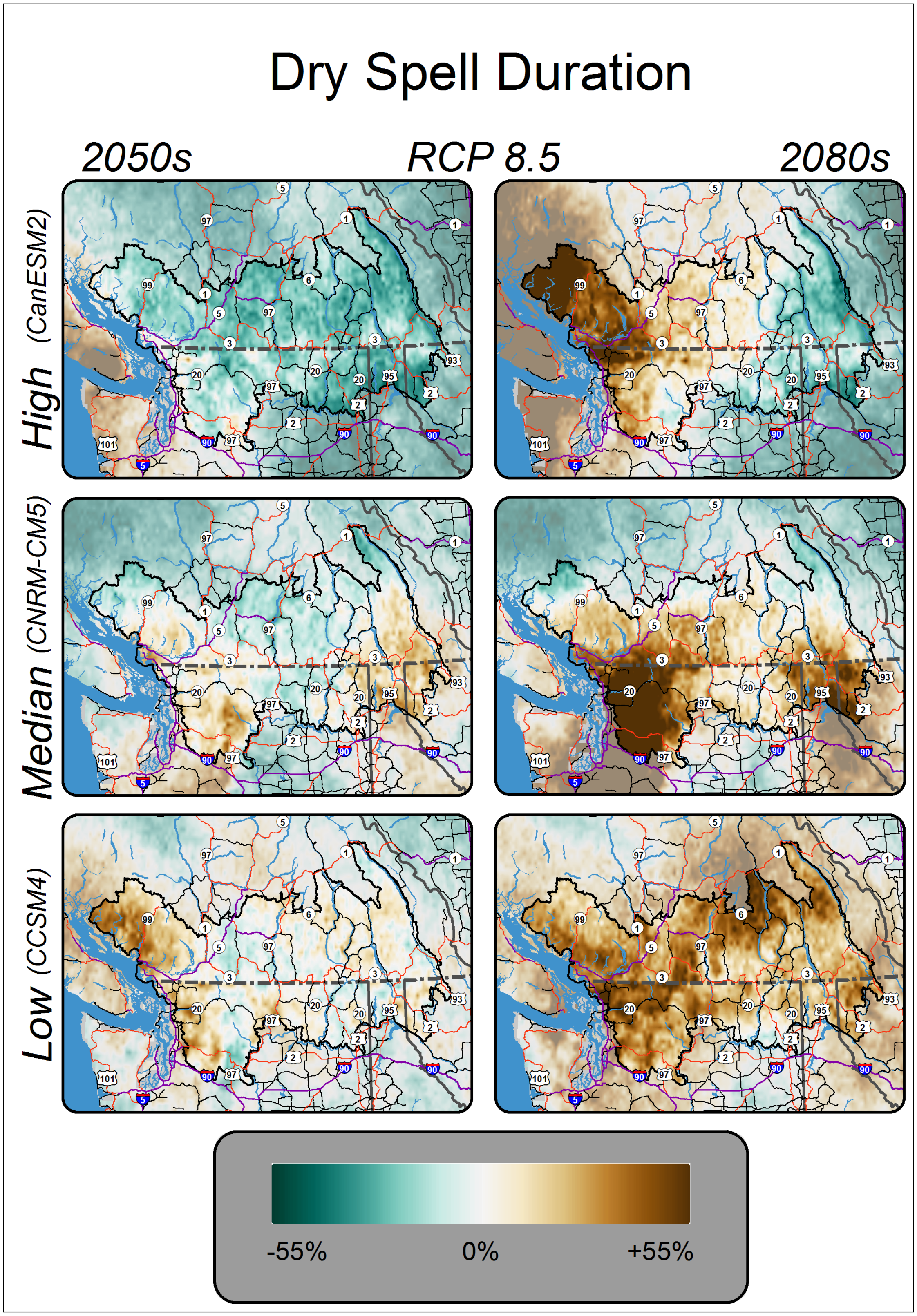
Appendix K.4g. Dry Spell Duration

ii) Extent: Okanagan-Kettle Region



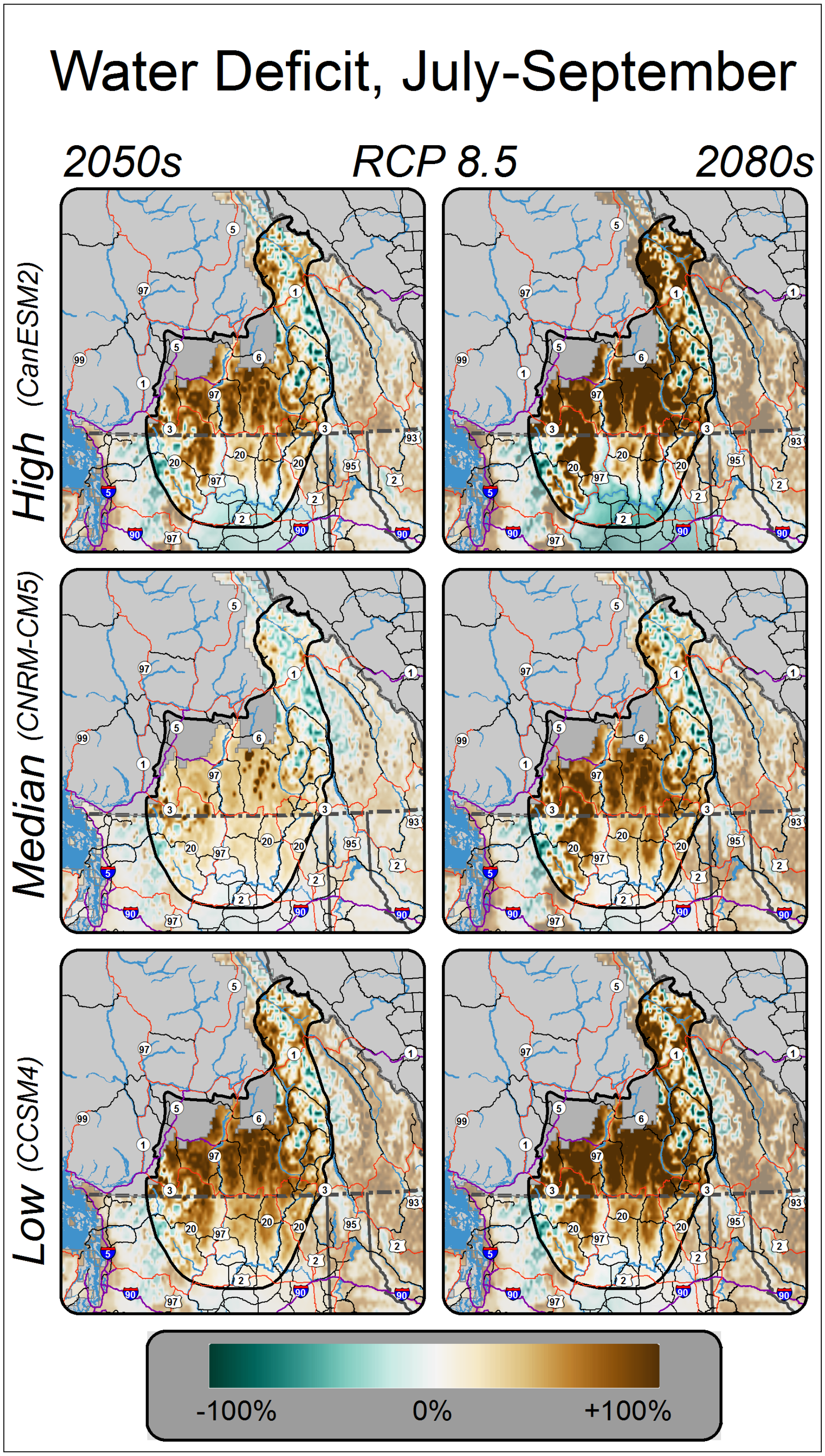
Appendix K.4g. Dry Spell Duration

iii) Extent: Washington-British Columbia Transboundary Region



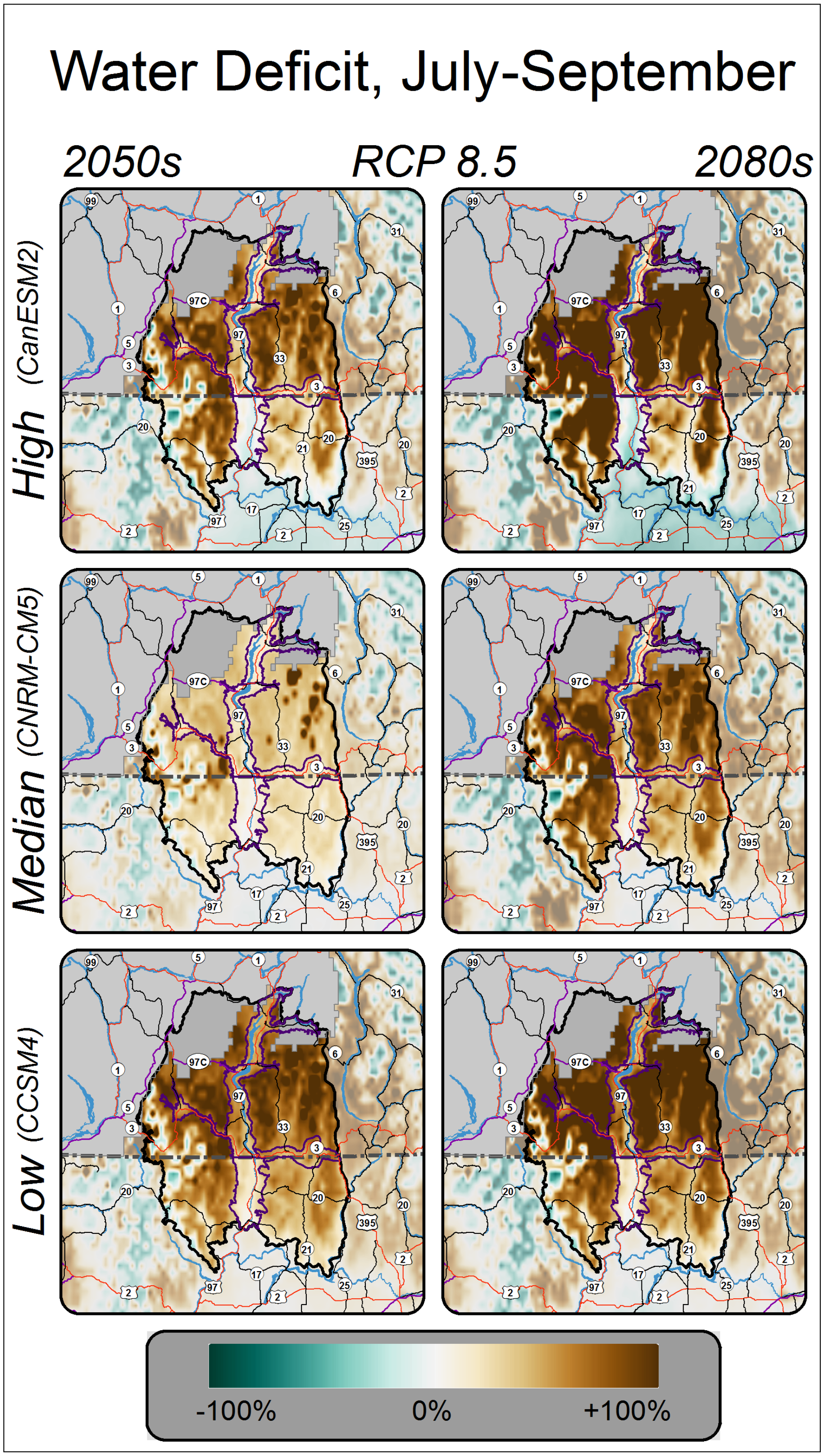
Appendix K.4h. Water Deficit, July-September

i) Extent: Okanagan Nation Territory



Appendix K.4h. Water Deficit, July-September

ii) Extent: Okanagan-Kettle Region



Appendix K.4h. Water Deficit, July-September

iii) Extent: Washington-British Columbia Transboundary Region